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PRATT & WHITNEY AIRCRAFT
DEPENDABLE ENGINES

Pratt & Whitney Aircraft
FLORIDA RESEARCH AND DEVELOPMENT CENTER

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FOR PHASE III OF THE
SUPERSONIC TRANSPORT DEVELOPMENT PROGRAM.

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REPORT E.

TEST AND CERTIFICATION PLAN (U)

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Pratt & Whitney Aircraft DIVISION OF UNITED AIRCRAFT CORPORATION
FLORIDA RESEARCH AND DEVELOPMENT CENTER

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Volume III
Report E

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SUMMARY

This report presents the Test and Certification Plan proposed for the prototype JTF17 engine for the supersonic transport and includes the following sections:

Section I, Introduction: A description of the overall Test and Certification Plan and of the procedures, facilities, and organization to be used in accomplishing this plan.

Section II, Component Development Test Plan: A detailed description of the proposed programs for development of individual prototype engine components, including descriptions of the test rigs, facilities, special instrumentation, and procedures to be used.

Section III, Engine Development Test Plan: A detailed description of the planned Phase III prototype engine development program leading to successful completion of the Flight Test Substantiation Test and the 100-Hour Prototype Flight Test Program.

Section IV, Flight Test Status: A description of the Flight Test Status Test to be conducted and of the other specialized tests planned during Phase III.

Section V, Flight Test Program: A description of the proposed program contributing to and supporting the 100-Hour Prototype Flight Test Program, including engine-inlet compatibility testing at AEDC.

Section VI, Engine Certification Plan: A brief summary of the proposed Phase IV development program leading to Engine Certification, the proposed Engine Certification Test, and the sustaining engineering program required to support the engine in airline service.

The test objectives and test plan scheduling, including the major milestones, are described in each of the sections listed above. Actual experience with other engine programs regarding numbers of active engines and parts required, test hours achieved, and types of tests to be conducted is provided for comparison.

The current status of the Phase II-C test program and the relationship and continuity of the Phase II-C test program to the Phase III test program are briefly described. All sea level and altitude testing is described, including the estimate amounts of each type of testing and the specific test requirements. This testing includes sea level static testing and simulated altitude testing at FRDC and the East Hartford Willgoos Laboratory and at such Government facilities as the Arnold Engineering Development Center at Tullahoma, Tennessee.

SECTION I
INTRODUCTION

The approach to testing, types of tests, methods of obtaining data, facilities utilized, and instrumentation technology planned for the JTF17 program are derived from the successful development of the J58 engine, which is the only engine in operational service today that was developed for sustained Mach 3 cruise. The J58 engine has accumulated over 22,000 hours of total test time with over 8000 hours of heated inlet time (Mach 1.5 or higher) and over 3500 hours of environmental time at Mach 3.0 and higher. A substantial number of the hours of flight time have been accumulated in the YF-12 and SR-71 aircraft. This development program included the successful completion of a Flight Suitability Test and a Model Qualification Test and subsequent uprating of the engine for increased thrust and improved TSFC. In addition to this high Mach number development experience, the more than 39 million hours of commercial service by such Pratt & Whitney Aircraft engines as the JT3C, JT3D, JT4, and JT8D provide the background of experience necessary to successfully develop a reliable, durable, and economical SST powerplant.

Functional descriptions of each of the Pratt & Whitney Aircraft organizational groups involved in the development of the engine and components follow. The system of program management used at P&WA and the interrelation of program management to the functional departments are described in Volume V, Report I.

A. DESIGN

During the engine and component test programs of the Phase III, design support will be required to evaluate data, recommend additional testing required, and provide design improvements and modifications. Commercial and military engine development experience has shown that problems involving component efficiencies, burner profiles, lubrication systems, and other areas will occur. To continually update the design and meet such problems, a qualified, experienced engine design organization will be assigned for this entire program.

1. Development Testing Design Support

Experience indicates that design modifications may be required during development testing for items such as:

1. Improvement in lubrication, scavenging, and seal cooling
2. Combustor cooling and fuel and airflow distribution
3. Improvements to minimize local unpredictable wear
4. Modifications to gearing to eliminate unpredictable resonances
5. Modifications of blade damping capability (root dampers, shroud dampers), if testing indicates need for refinement
6. Component mounting and plumbing changes required because of engine vibration environment
7. Design changes for improved ease of maintainability as indicated by assembly and disassembly experience

8. Modifications to improve ma·facturability as determined by experimental engine fabrication experience
9. Changes indicated as a result of value engineering analysis
10. Test plan and instrumentation recommendations to improve data collection and effectiveness
11. Confirming analytical design effort to verify design criteria as test results are obtained. This will include such areas as engine heat rejection, thrust balance, turbine cooling, aerodynamic design, and temperature prediction for cooling effectiveness.
12. Continuing review of materials capability and advanced materials and techniques to improve engine durability
13. Weight analysis of all parts and assemblies to ensure achievement of minimum weight consistent with performance and durability objectives
14. Determination of rig and part testing required to support engine test analysis of results
15. Continuing trade studies of performance, reliability, and weight to maintain desired balance of achievement.

2. Design Effort During Ground Testing

Design effort during ground testing will continue to be directed toward the support required for achievement of program objectives and will also include the following:

1. Modifications required as a result of engine-airframe interface experience, such as modifications for accuracy of connection points, accessibility and control leakage, and power takeoff alignment
2. Analysis of effects of operation with actual system flexibilities and vibration environment
3. Analysis of installed fuel, lubrication, and hydraulic systems
4. Evaluation of inlet system compatibility and unstart during AEDC testing.

3. Design Effort During Flight Test

Design effort during flight testing will be directed toward the achievement of program objectives by re-evaluation of the basic design with consideration of test data and redesign and modification support as required. In addition to the support previously mentioned, specific support during flight testing includes:

1. Analysis of heat rejection data and breather and lubrication system performance
2. Verification of as-installed engine thermal environment

3. Evaluation of all engine-airframe interface systems including cabin bleed, inlet conditions, controls, and power takeoffs.

B. FABRICATION (See Volume V, Report G.)

1. Equivalent Sets of Parts

JTF17 Project Engineering authorizes all development parts procurement by issuance of the Engineering Order Supplement, which defines the task to be accomplished and specifies the detail hardware requirements. This hardware is scheduled by quantity and date to predicted needs determined by Project Engineering by considering the effective useful life of the part and engine test hours accumulated per month. Required quantities of burner or turbine parts might thus be greater than requirements for major engine cases. The total quantity of test support parts required over a period of one year can be expressed as equivalent sets of parts:

$$\frac{\text{Total Cost of All Test Support Hardware}}{\text{Average Cost of a Development Engine}} = \text{Number of Equivalent Sets}$$

The number of equivalent sets of parts and average number of engines predicted for the JTF17 development effort are as follows:

Year	1967	1968	1969	1970	1971	1972	1973	1974
Average No. of Engines	4	7	11	12	14	15	15	13
Equivalent Engine Sets	11	12	12	12	12.5	10.5	7.5	7.5

2. Release of Requirements

Drawings are released from Design to Project Materials Control (PMC) by an Experimental Release. PMC orders and schedules the parts and works directly through Purchasing for subcontracted hardware and through Materials Control for hardware made in-house. Technical problems that arise during fabrication are resolved by PMC Engineers working with Experimental Engineers or with specialists in Process Planning or the Materials Laboratory.

3. Manufacturing and Subcontracting

PMC writes Requirements Cards from the Experimental Release and submits the cards to a panel of manufacturing specialists for a "Make-Buy" recommendation. Hardware designated "make" is submitted to Materials Control. Process Planning writes Operation Sheets and, if necessary, Tool Design requests and the job order is released to the shop for manufacture. PMC writes Requests for Purchase Orders (RPO) for hardware designated "buy." The order is placed by competitive bidding or with an Approved Engineering Source by Purchasing. In either case, the promised completion or delivery dates agree with the requested dates specified by Project Engineering. If this cannot be done, the matter is brought to the Program Manager for resolution.

Purchasing and Materials Control monitor progress of the hardware. Slippage in completion date is immediately reported to PMC so that sufficient priority may be applied to improve delivery or so that Project Engineering may be informed to revise test programs.

The PMC organization effects rapid incorporation of design changes, a necessary requirement in the engine development program. Most changes are discussed prior to design release by Project Engineering and the PMC Engineer. "Hold" instructions are issued if necessary until formal drawings are available. Hardware obsolescence is thus held to a minimum.

The Experimental Engineer can authorize the rework of used parts directly from the assembly floor. Rework of this type carries a high priority since it is usually incorporated directly into a test engine.

4. Inspection and Allocation of Parts (See Volume IV, Report F, Section III.)

All raw material, when received, is inspected by the Materials Control Laboratory for compliance to specifications and by Quality Assurance for dimensional requirements. All finished purchased parts are inspected by Quality Assurance for compliance to the drawing and, where applicable, are submitted to the Materials Control Laboratory for testing. Nonconforming raw material and finished parts are held by Quality Assurance for disposition. By arrangement with Quality Assurance, finished parts may be inspected at a subcontractor's plant.

Parts meeting quality standards will be sent to Finished Stores until requisitioned for incorporation into machined assemblies or for assembly into a JTF17 engine or rig.

5. Fabrication and Tooling (See Volume V, Report G.)

Design of tools reflects the quality of parts likely to be produced and the probable stability of the part configuration. The "Make or Buy" decision for tools is made by Materials Control after a review of the Tool Room load, schedule requirements, and cost. Tools not made in-house will be placed with tool subcontractors on the basis of competitive bids. Upon completion, all tooling will be inspected by Tool Room Inspection. Final release of the tool for use in manufacture will be made only after first piece checkout under the guidance of the cognizant Process Planning Engineer.

6. Inspection Tools

Quality Engineering determines the need for gages to inspect parts or assemblies from the Requirements Card submitted by PMC. These may be special gages such as pressure test fixtures, disk etching fixtures, etc., which are processed in the same manner as fabrication tools, or catalogue items such as plug gages and thread gages, which are processed by Gage Standards. Special gages in the development program are limited to operations that cannot be done by layout or dimensional inspection.

Gage Standards inspects all gages and after acceptance, sets up regular reinspection to insure continued accuracy.

7. Assembly Tooling

Assembly tooling requirements such as transport stands, special wrenches and torque or stretch measurement devices, pushers and pullers, balance tooling, spin pit arbors, alignment tools, handling stands, and hoists originate from the Assembly Planning Section of Process Planning from a study of the engine layouts. "Make or Buy" decisions, subcontracting, manufacture, and inspection are handled in the same manner as other shop tooling.

8. Test Tooling

In general, test tooling is made by special request since it is usually a duplicate of other Assembly Floor tooling. Test tooling is limited to a few items that warrant duplication of tooling available on the assembly floor.

C. ENGINE ASSEMBLY - ENGINE CONFIGURATION

An Experimental Engineer is assigned to a new development engine build several months before the required assembly date. The Experimental Engineer works closely with PMC to determine the status of parts and with Design to familiarize himself with engineering changes in process. He is responsible for defining the general configuration for the engine in accordance with instructions from his Project Engineer. PMC then issues a parts list to authorize delivery of the parts from Experimental Finished Stores.

Engine rebuilds are handled in a similar manner, but a complete definition of parts cannot be established until inspection after disassembly.

New parts, issued by Project Materials Control, are delivered to Assembly to assemble as an engine or rig. Records of the parts issued are maintained with the engine or rig and assembly work done is by written instructions from the assigned Experimental Engineer. Parts requiring special cleaning and handling, are cleaned and packaged in preparation for assembly. Reoperation requests are processed on Work Orders by Assembly personnel and shortage records are also maintained. Parts tables are segregated and kept orderly by Parts Table Attendants. The Shift Superintendent of Assembly conducts daily shortage meetings and scheduled build meetings to control engine and rig build schedules. During the build of the engine or rig, problems encountered are recorded on Deviation Reports, which are used as a means of conveying design or deviate part problems to Engineering, Quality Assurance, and PMC (including suggestions for product improvement). Assembly Problem Reports are written to point out corrective action necessary on faulty assembly, damaged parts, or abnormal conditions. After completion of an engine or rig build and delivery to Test, all parts not used in the current build are either returned to Finished Stores (if new) or, in the case of used parts, sent to Used Stores.

Engines and rigs returning from Test are disassembled in accordance with the written instructions of the Experimental Engineer. Parts requiring cleaning prior to inspection are processed through the Assembly Cleaning Section, and electrical harnesses and probes are serviced in the Assembly Probe Crib in preparation for the next build.

In addition to engine and rig build service, the Assembly Department provides and installs all special pressure and temperatures instrumentation. The Assembly Department provides an engine mockup section with tube bending facilities so that Design and Project Engineering can maintain up-to-date engine plumbing and control system schemes at all times. The Assembly Department also provides a test repair crew for engine and rig repairs in the Test Areas and a small Machine Shop to expedite simple machining needs and special tool repairs.

Shop supplies and perishable tooling used to support Engineering requirements are maintained by Assembly as well as the coordination of all special project tooling. In addition, the department provides a complete and current blueprint file for use by Assembly and Engineering personnel.

Special instructions to cover processes and materials as directed by Engineering Instruction or bulletins are issued by the Superintendent of Assembly. These are called Experimental Assembly Instructions (EAI). Experimental Assembly Operating Procedures covering internal methods of operation affecting tooling, parts handling, and approved methods of operation are issued from the Assembly Office.

To fulfill their service obligations, the Assembly Department provides for adequate floor space based on the number and size of the units planned by Engineering and provides the necessary security enclosures compatible with the degree of security designated by the project. Special equipment such as flow benches, balance machines, spin testing,cleaning equipment, hoists and lifts, work benches, and parts tables are provided and maintained to process engines and rigs through the assembly and disassembly cycles. These items of equipment also provide fulfillment for the manufacturing in-process parts requirements such as balancing, pressure test, spin zyglo, and proof spinning.

D. EXPERIMENTAL TEST OPERATIONS

Experimental Test Operations, under the direction of the Chief of Experimental Test, is a direct support group to Project Engineering and has the responsibility for all phases of development testing of engines and related hardware. Test operations for jet engine development are handled by Turbojet Engine Test, a department within Experimental Test Operations. The responsibility for all jet engine and component hardware testing rests with this group. Groups supporting this department are Instrumentation, Test Support Shop, and Facilities Service, each headed by individual supervisors, (figure 1).

The Turbojet Engine Test Department directed by the Superintendent of Turbojet Engines Test accepts test engines and/or component hardware from the Assembly section of Experimental Manufacturing and conducts various development test programs. These programs consist of sea level and altitude calibrations, specific fuel consumption programs, and/or long term endurance programs on various engines, rigs and component hardware. The engine or engine component is received from Experimental Assembly with an instruction sheet from the Project Engineer or his Experimental Engineer defining the specific tests. The engine or component is mounted in one of a number of test stands, depending upon the test program. Data are acquired from the engine or engine component by means of automatic data acquisition and manual instrumentation.

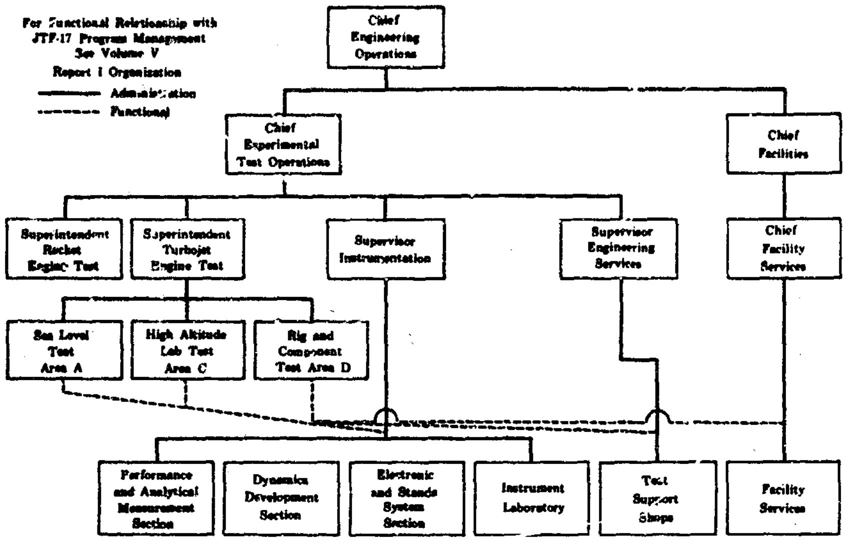

Figure 1. Experimental Test Organization FD 17033
EI

1. Instrumentation Group

The supporting Instrumentation Group is made up of four sections: The Performance and Analytical Measurement Section, Dynamics Development Section, Electronic and Stand Systems Section. These are under the direction of individual Project Engineers, and the Instrument Laboratory is under a General Supervisor.

1. The Performance and Analytical Measurement Section is responsible for liquid flow measurement, gas flow and traversing measurement, temperature measurement, thrust measurement, pressure measurement, and combustion and environmental tests.
2. The Dynamics Development Section is responsible for dynamic analysis, sound, stress, and vibration measurement.
3. The Electronic and Stand Systems Section is responsible for calibration laboratory services, test stand control systems, electronics applications, and design and development.
4. The Instrument Laboratory maintains and repairs all electronic, pneumatic, hydraulic, electrohydraulic, electromechanical, and environmental instruments used for data acquisition and calibration. All calibrations of instruments are traceable to the National Bureau of Standards.

2. Test Support Shop

The Test Support Shop maintains all test facilities in respect to repair, modification, cleaning, fabrication, and installation of test equipment.

3. Facility Services

Facility Services is headed by the Chief of Facility Services, reporting to the Chief of Facilities and maintains equipment such as electrical systems, all auxiliary air systems, water systems, fire systems, building, and grounds throughout the test areas.

The three test areas, under individual supervisors, have the following capabilities:

1. Area "A" (figure 2) performs sea level testing. It is equipped with seven engine test stands, two of which have heated inlet capabilities of 800°F at Mach 3. A burner stand is available for testing of burners, flameholders, spraybars, or turbine vane and blade rigs.

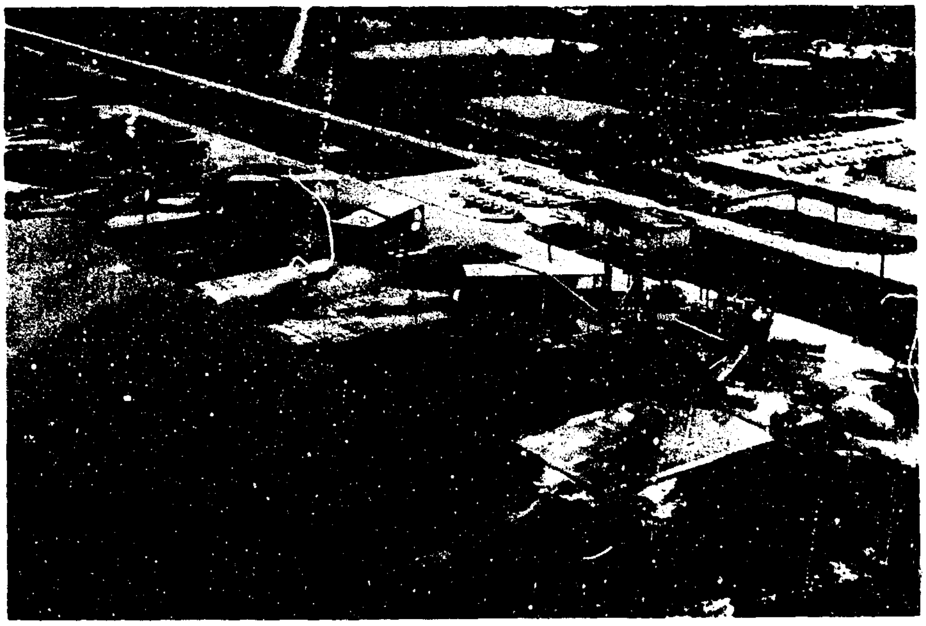

Figure 2. Test Area "A" FC 13339 EI

2. Area "C" (figure 3) performs altitude testing. Two engine test stands, one compressor stand, and two burner stands are available.

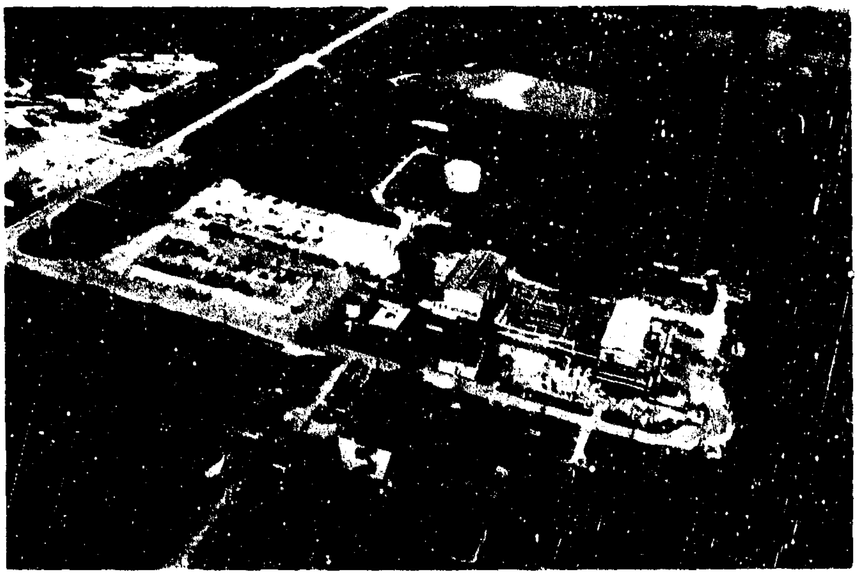

Figure 3. Test Area "C" FC 13345 EI

digital computer used to process raw data into engineering units. Computed performance parameters such as TSFC, simulated altitude, Mach number, exhaust gas temperature, EGT profiles, component efficiencies, and airflow are displayed to the engine Experimental Engineer at the test stand control room while the test is in progress within 2 to 3 minutes from the time of recording.

The development of advanced turbofan engines, such as the JT3D, JT8D, and TF30, and the high Mach number, high thrust J58 have made it necessary to maintain a high-level program of instrumentation development. The techniques and experience acquired in the development of these engines are now available for the JTF17 engine program.

The Instrument Laboratory is equipped and staffed to develop, maintain, and calibrate all types of precision instruments required for propulsion system, component development, and performance measurements. The laboratory is staffed with 227 technicians and laboratory supervision personnel. A total of 12,000 square feet of floor space is devoted to electronic instrument development and construction, instrument welding and machining, maintenance of standards for calibration, and maintenance and calibration of a wide variety of instruments. Equipment is available for measuring and recording fuel flow, thrust, speed, pressure, vibration stress, chemical composition, heat transfer, and numerous other variables associated with powerplant evaluations. An additional 3,500 square feet are located in other buildings on the plant site for data recording system maintenance, and strain gage development and application.

Because of the wide ranges of parameters, high degree of accuracy, and extremes of environment in present day testing, the instrument systems required are necessarily sophisticated. The engineering staff provides the technical direction for the work of the Instrument Laboratory, has responsibility for providing all necessary specialized measuring instruments, plans and supervises the assembly of complex measurement and recording systems, and does the actual measurement and analysis in cases where specialized experience is necessary.

1. Dynamic Measurement Section

a. Strain Measurements

Virtually every rotating and stationary part of an engine is instrumented with gages during development testing. In addition, these tests go on throughout the service life of the engine to refine the product even further. All aspects of strain gage instrumentation, from installation to data analysis, are performed within the Instrumentation Group with close liaison with the engine development groups and the design analytical personnel. The techniques and knowledge of strain measurements in the Instrumentation Group are the result of over 28 years of experience.

Since no commercially available system of strain measurements has ever operated successfully in the environmental extremes that occur in jet engines, Pratt & Whitney Aircraft has pursued an agressive development program designed to produce strain gage installations equal to the task. This program has been carried on at both Pratt & Whitney Aircraft and through development contracts with Battelle Memorial Institute. The result has been to push the operating temperature limits of dynamic strain measurements to 2300°F and of static strain measurements to over 1000°F. Years of experience in successfully developing techniques for

3. Area "D" (figure 4) tests components and rigs. There are 42 stands available for testing of major and minor fuel components, actuators, gearboxes, seals, bearings, oil and fuel pumps, and ignition components.

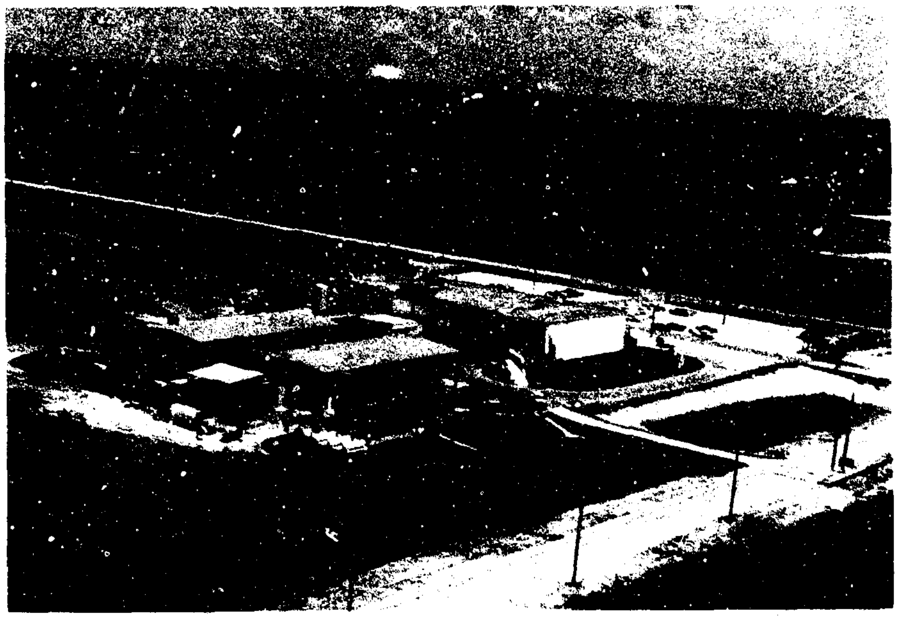

Figure 4. Test Area "D" FC 2054 EI

E. INSTRUMENTATION

The experimental evaluation of gas turbine engines requires the accurate measurement of gas and metal temperatures, gas and fluid pressures and flow rates, and thrust. Engine durability requirements necessitate the accurate measurement of vibration, position, and stress data.

In the application of instrumentation the following conditions must be met:

1. Ideally, the instrumentation must not affect the performance of the rig or engine under test, or alter the properties of the material to which the instrumentation is attached. Practically speaking, these effects should be minimized.
2. The instrumentation must provide data of sufficient accuracy to satisfy the test requirements.
3. The instrumentation must be durable enough to provide data for a period of time commensurate with test objectives.

Pratt & Whitney Aircraft has developed techniques to satisfy these conditions, particularly in the area of miniaturization and automated data recording systems. Automated digital data systems have been applied to jet engine development testing at FRDC since 1958. Two data systems, serving 10 jet engine or component test stands, have produced an average of 2.6 million data points per month over the last two years. Reliable and consistent data have been taken at environmental conditions in excess of Mach 3.0. Included as part of the systems is an on-line

digital computer used to process raw data into engineering units. Computed performance parameters such as TSFC, simulated altitude, Mach number, exhaust gas temperature, EGT profiles, component efficiencies, and airflow are displayed to the engine Experimental Engineer at the test stand control room while the test is in progress within 2 to 3 minutes from the time of recording.

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strain gage installations to overcome the unique combination of stress measurement at high temperatures and in high centrifugal fields has reduced this formidable problem to one of almost routine nature.

(1) Strain Measurements on Rotating Members

(a) Standard Slip Rings

The portion of the test program designed to ensure the structural integrity of the rotating parts is an important phase in the development of gas turbine engines. Currently this is best accomplished by using strain gages applied to the parts in question, from which resonant frequencies and strain amplitudes over the engine operating range are determined. This need has resulted in a highly developed instrumentation system of which the slip ring is an essential part. Slip rings at Pratt & Whitney Aircraft have evolved into a medium speed device of very durable construction, suited to the rugged environment encountered in engine test work. The standard slip ring is compact and has the capability of transferring signals from 24 strain gages on thermocouples at speeds to 25,000 rpm. One of the unique features of the Pratt & Whitney Aircraft design is the capability of stacking several units together to accommodate up to 96 channels. Adaptions of the standard design have been used at speeds up to 50,000 rpm. Strain gage data have been obtained during flight tests of the J58 turbojet engine.

(b) High Rotor Slip Rings

Two-speed axial flow jet engines require a special slip ring design to transfer strain gage and thermocouple information from the high rotor which, because of its geometry, cannot be instrumented with a standard slip ring. Each high rotor slip ring must be specifically designed to fit each type of engine. High rotor slip rings have been designed and successfully used in the JT3D, JT8D, and TF30 engines. A high rotor slip ring is designed for the JTF17 engine.

(c) Strain Gage Telemetry

The high rotor slip ring, while a proved data acquisition system for both stress and temperature investigations, is often limited by space requirements as to the number of data channels available. Ten years ago, Pratt & Whitney Aircraft successfully developed a battery-powered, 12-channel, pulse amplitude, modulated telemetry system for stress investigation on engine high rotor parts. Recent advancements in the development of miniature solid state electronics has led Pratt & Whitney Aricraft to undertake the development of another high rotor telemetry system with the advantage of increased number of data channels available From 24 to 40 miniature FM transmitters, each representing a dynamic strain information channel, can be mounted directly on the rotating parts. The strain gage output directly modulates the FM carrier frequency, which is transmitted to a stationary antenna where it is subsequently detected and recorded.

2. Acoustic Measurements

In recent years, jet noise sources have become important problems for noise control. In the case of the turbojet and turbofan engines, noise control is necessary to avoid structural fatigue of the airframe or annoyance to personnel within the airplane or in the airport neighborhood. Effective noise control

must begin with accurate identification of the noise spectra as to frequency and pressure spectrum level of discrete frequencies. The source of the noise must be identified (i.e. compressor whine, exhaust jet, etc.) before effective control can be attempted.

Jet engine noise studies began at Pratt & Whitney Aircraft in 1953, several years before the operation of scheduled jet transports in this country. Tests were conducted to gain an understanding of jet engine noise generating mechanisms, and many suppressor devices were tested and evaluated. During these test programs, extensive facilities and techniques were developed. These facilities and the experience developed are available for the required noise measurements on the JTF17 engine.

Noise tests of full-scale jet engines have been conducted using the outdoor test facilities shown in figure 5 including a permanently installed system of 21 microphones, spaced along a 150-foot radius from the engine used for "far-field" noise measurements. A tower, located near the engine, supports cables to which microphones are attached for measuring asymmetrical noise radiation patterns. Additional stationary microphones, close to the test engine, are used for making "near-field" noise measurements. Signals from 10 microphones are recorded simultaneously by the sound recording console shown in figure 6.

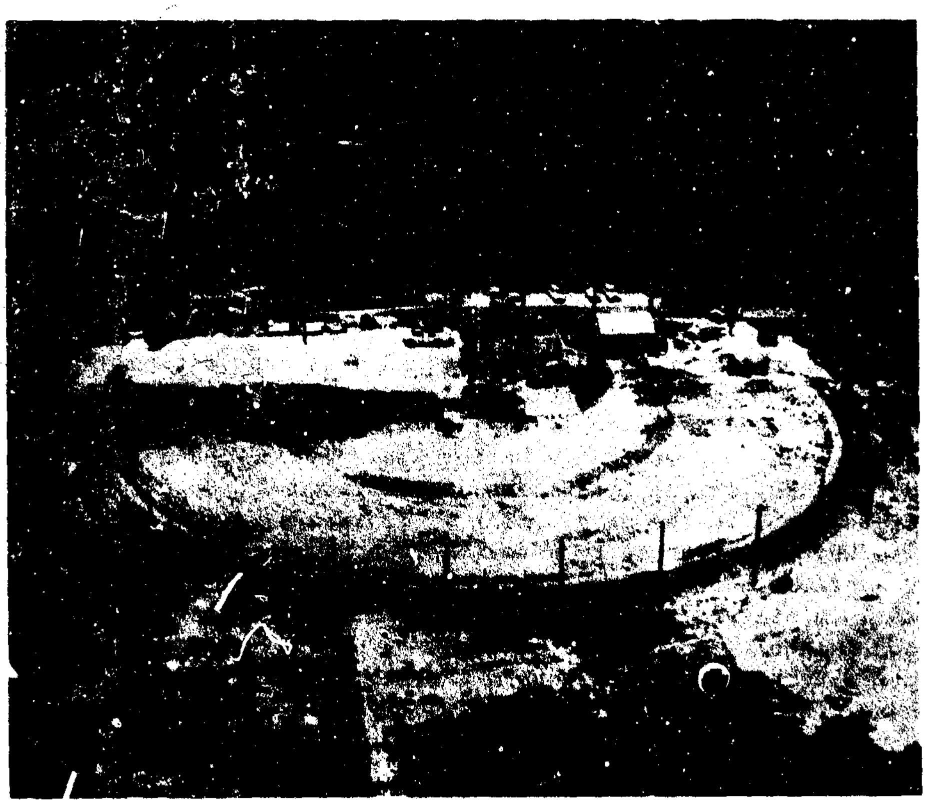


Figure 5. Bradley Field Full-Scale Engine Noise Test Area

M 7474
EI

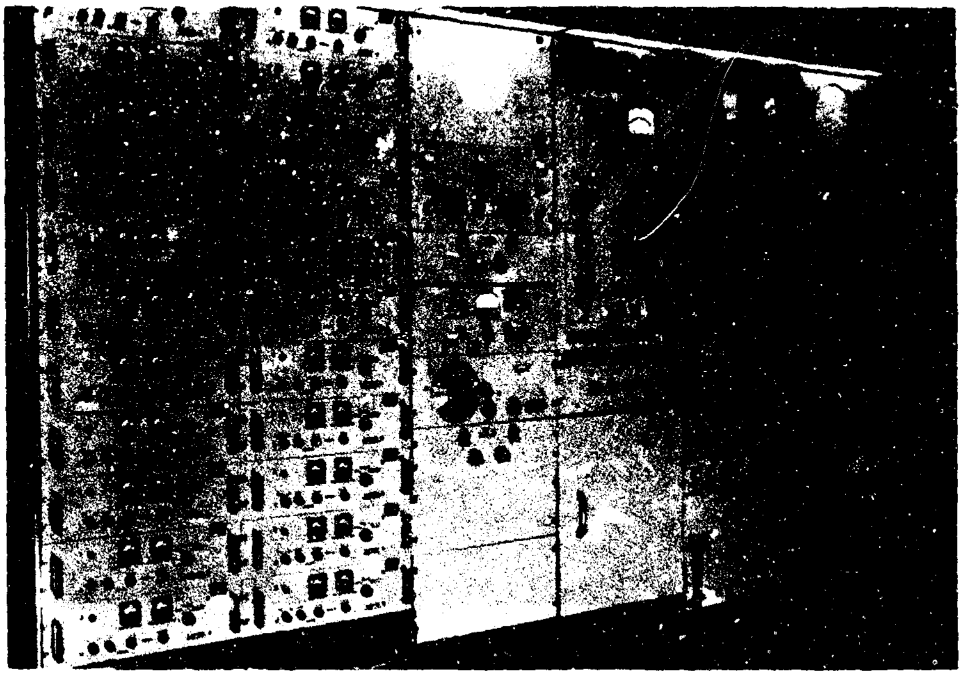


Figure 6. Bradley Field Sound Recording Console X 13246
EI

A new test stand facility, A-9, which will be completed at FRDC in April 1968 will be ideally suited for documenting noise measurements and will include the following features:

1. Low ambient noise levels in a remote area
2. Carefully graded and cleared ground surface
3. Facilities and instrumentation for engine performance measurements
4. Permanently installed instrumentation for monitoring meteorological conditions
5. A permanently installed system of 20 microphones spaced along a 300-foot arc centered on the engine exhaust nozzle. This system will be used for "far-field" measurements.
6. Provisions for the installation of microphones in any desired pattern in the "near-field" of the engine
7. A permanently installed sound data recording console which includes a 14-channel magnetic tape recorder, microphone power supplied, line driven amplifiers, and accessory electronic equipment required for microphone system calibration and monitoring. A second 14-channel portable tape recorder will be available for a total of 28 channels of data recording.

a. Calibration

To maintain measurement accuracy for all noise measurements, all microphones are periodically calibrated. The standard microphone used in calibrations is traceable to the NBS. The calibrating facilities are shown in figure 7.

Figure 7. Microphone Calibration Instrumentation XP 22888
EI

b. Data Reduction

Special equipment is used for the reduction of tape recorded noise data. An octave-band analyzer console is shown in figure 8. The output of the console is in the form of punched cards. These cards are input to an electronic digital computer. Narrow-band frequency analysis of steady-state noise data is accomplished by the equipment shown in figure 9.

Figure 8. Automatic Octave Band Noise Analyzer XP 50952
EI

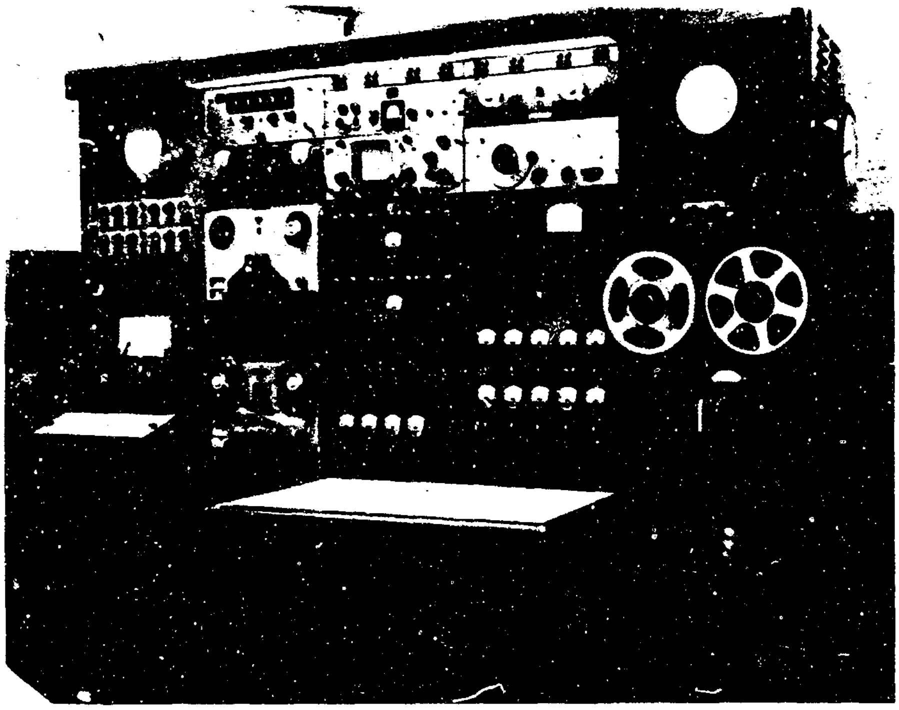


Figure 9. Noise Data Reduction Console X 10475 EI

c. Data Analysis

Several computer noise analysis programs have been developed to translate raw acoustical data into more meaningful forms. Computer output data include such variables as perceived noise levels, loudness levels, and octave band and over-all sound pressure levels. These variables are recorded at a wide range of distances from the engine. Model nozzle test data are also corrected to full scale and constant altitude data by the use of computer programs.

Empirical relationships between noise, engine design, and performance features have been established and incorporated in a computer program used to estimate the noise from an acoustically untested engine or the effect on noise of modifications to existing engines. Sound pressure level at the various angles and distances can be predicted by extrapolation on the computer. These relationships, along with raw acoustic data, are used as input to the noise analysis computer programs.

Through the use of the acoustic facilities in extensive sound test programs on both turbojet and turbofan cycle engines, Pratt & Whitney Aircraft has developed an understanding of the relationships between engine design and noise generation. This experience is incorporated into the design of new jet powerplants to minimize engine noise.

3. Vibration Measurements

The vibration instrumentation techniques and systems adapted or developed at FRDC in support of the existing or previous projects are directly applicable to

the requirements of the JTF17 engine development program. No situations have been encountered in the Phase II-C program that indicate unique problems or technological requirements beyond the level P&WA is equipped to handle on an everyday basis.

The over-all vibration measurement system can be considered as the following subsystems:

a. Transducers

Self-generating transducers, either velocity pickups or piezoelectric accelerometers, are used at FRDC. The choice depends upon the specific measurement situation. Velocity pickups require no signal conditioning except that performed in a monitoring instrument. When the frequency range, dynamic range, size and weight limitations, temperature, and vibration environment, and endurance considerations permit, velocity pickups are normally used because of simplicity of the readout system. If one or more of the above factors preclude the use of velocity pickups, piezoelectric accelerometers are used. The experience at FRDC has been that for all vibration measurement situations, piezoelectric accelerometers can satisfy any requirement that velocity pickups will with higher resultant accuracy.

One of the most severe environmental considerations for a high Mach engine instrumentation is high temperature. Vibration transducers which will operate at 700°F are used on a routine basis at FRDC. If measurements are required in areas where temperatures exceed 700°F, supplemental cooling is supplied. Cooled fixtures have been developed which permit the use of standard commercial transducers at any location on a turbine engine operating in a Mach 3 environment. Where cooling by expendable ground support coolants is not available, fixtures are employed that are cooled by engine fuel or lubricants.

b. Monitoring or Indicating Instruments

The majority of the monitoring of engine vibration employs a meter readout of vibratory displacement within the frequency range above the lowest rotor rotational frequency. The vibratory displacement analog as derived from an accelerometer is accurate over a wider amplitude and frequency range than the vibratory displacement analog derived from a velocity transducer.

Monitoring systems involving both single integration of velocity signals and double integration of acceleration signals to a displacement analog are routinely used for engine and component vibration monitoring at FRDC.

Standard provisions on all engine test stands provide for 16 channels of monitoring in a displacement analog and 6 channels of acceleration passbands.

For some applications, a monitor of vibratory acceleration level is desired. An example is to detect the presence of combustion instability ("screech") in turbojet afterburners. For these applications, P&WA-designed readouts are employed that indicate the vibratory acceleration level in one or more preselected passbands. The passbands are determined by plug-in elements and are selected on the basis of analytical calculations of screech mode frequencies that may be excited. These indicators, since they are sensitive only to the excited vibration, permit an immediate indication of the presence of screech and levels may be quickly measured for comparison of parameters.

c. Recording Equipment

Monitoring instruments are designed to indicate the present integrity of test hardware or to establish a trend that would indicate degradation of test hardware. Vibration data recorded on magnetic tape permits detailed spectrum analysis, tracking analysis, and definition of transients and will also reduce total engine operating time of test.

On sea level stands there are fixed magnetic tape capabilities for 26 dynamic channels. In the altitude facility, the capability exists to record 13 dynamic data channels. Portable tape recorders are available when a larger number of channels must be recorded continuously.

Existing recording techniques and narrow band analysis employed on a routine basis permit the capture and resolution of frequency components 2000:1 below the overall data level. Record bandwidths of 0 to 10,000 cps are used for routine tests and a 0 to 50,000 cps capability exists when needed.

d. Environmental Vibration Laboratory

The dynamic analysis section of the instrumentation laboratory has the capability of testing specimens from 5 to 6000 cps with equipment generating forces to 84,000 pounds over a temperature range of -320°F to 1200°F.

Two vibration systems with random and sinusoidal capabilities are connected to a centrally located patch panel for maximum test flexibility. Magnetic tape recorders, oscillograph recorders, amplifiers, tracking analyzers, frequency counters, oscilloscopes, calibration equipment, and other related instrumentation have their inputs and outputs available at this central panel. One system contains the MB-C210 vibration exciter, figure 10, with the latest Model MB 5140 (240 KW) amplifier and automatic compensation equipment, figure 11. Figure 12 is a closeup of figure 10. This test was a stress survey of an inlet guide vane of the J58 engine in a 700°F environment. The heating unit and coverplate for the fixture were removed for the photo.

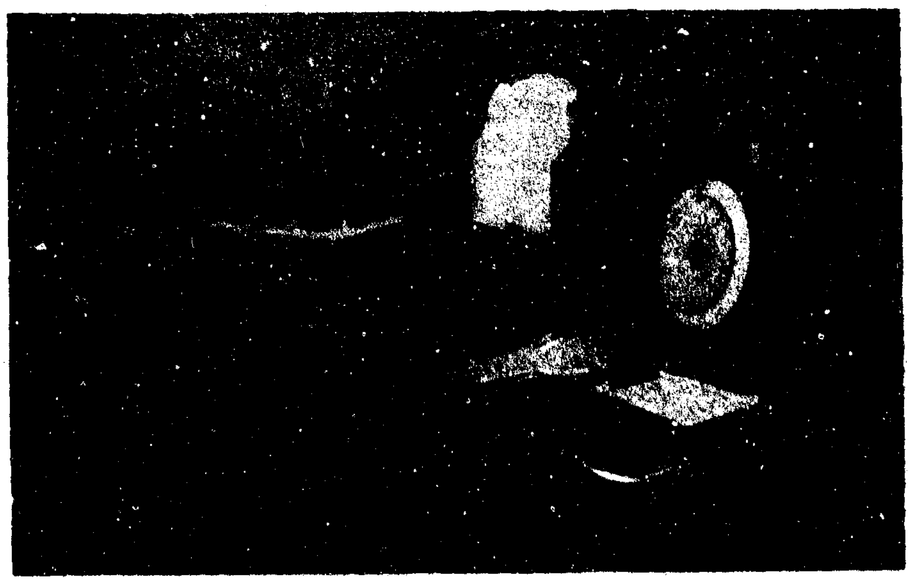


Figure 10. MB-C 210 Vibration Exciter FE 59050
EI

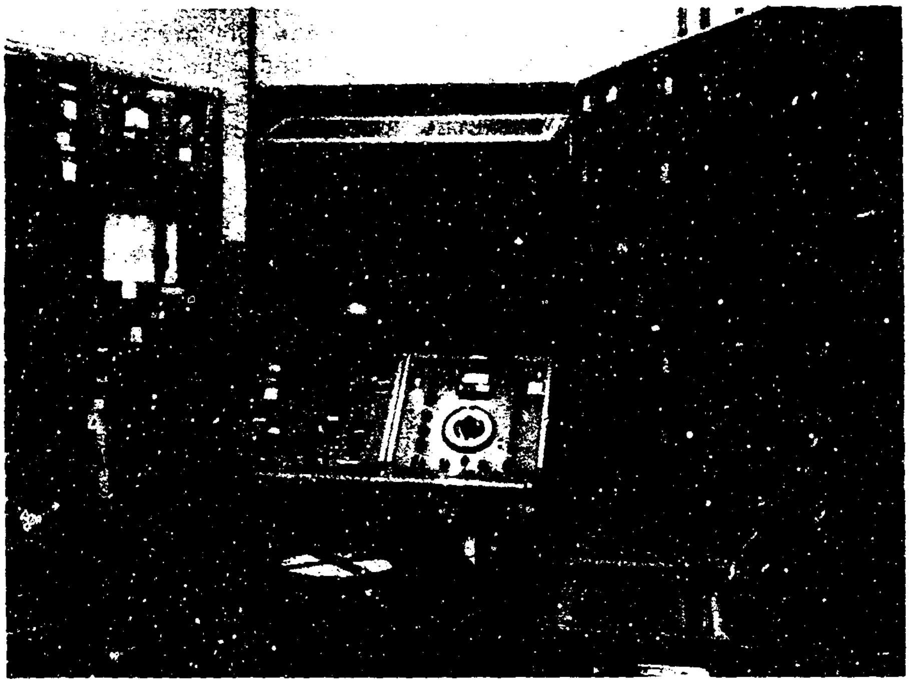


Figure 11. MB 5140 Amplifier and Automatic Compensator — FC 12944 EI

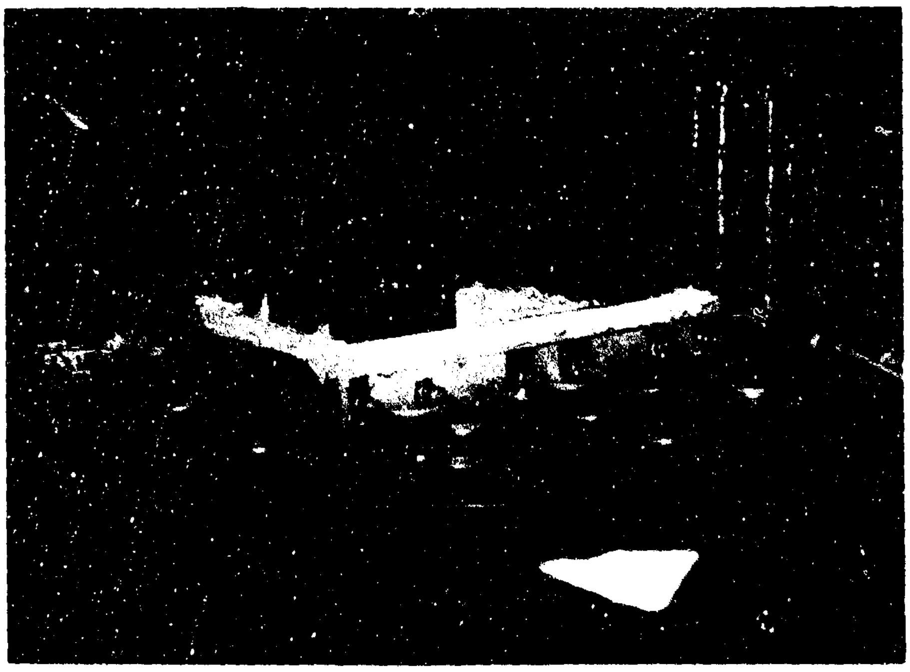


Figure 12. Closeup of MB-C 210 Vibration Exciter — FE 59051 EI

The MB Model T-388 automatic spectrum equalizer provides minimum setup time capability for random programs with equalization of the specimen realized within a few seconds. A flat or shaped spectrum is easily programmed on the control panel by adjusting slide potentiometers, each of which provides accurate equalization over a narrow bandwidth of 25 cps, and together cover a total spectrum of 2000 cps. Accelerometer limiting is available for eliminating a source of possible damage to the test specimen. Analysis of the generated spectrum is also accomplished using the Model T-388. Three types of readout are provided; direct reading in G^2/cps, continuous monitoring on the oscilloscope, and a documented record of the test using a multiple parameter recorder (independent abscissa and ordinate input).

Random vibration testing of smaller specimens can be performed using the Model MB-C10VB vibration exciter, whose sinusoidal peak force is 1750 pounds over the frequency spectrum of 5 to 6000 cps and 3150 pounds peak random over any 2000 cps band up to 6000 cps.

To ensure that the excitation levels being used for environmental vibration tests are valid and as requested, an analyzer capable of tracking one signal and rejecting all others is used.

In support of the J58 engine development program, these systems have been used extensively with addition of stress coat techniques and strain gages to study bending modes and stress areas of compressor and turbine disk or disk and blade assemblies, inlet guide vane sections, afterburner assembly and bypass ducts. This experience is directly applicable to the JTF17 program.

4. Continuous Engine Data Monitoring System

Investigation of nonrepetitive unscheduled engine operation that occurs during routine testing can result in time-consuming trouble-shooting programs using normal investigation procedures. To facilitate more rapid acquisition of such vital information, FRDC has developed a continuous engine data monitoring system that is used during all engine test runs.

A recording system, which serves two test stands, consists of a seven-channel magnetic tape recorder with certain channels multiplexed to give a recording capacity of eighteen channels. Data are recorded on the tape in both direct analog and FM form. Input signal conditioning networks are available to permit recording of different types of parameters. Types of data recorded are fuel flow, rotational speed, pressure, temperature, vibration, and mechanical position. A recording system is shown in figure 13.

The recorder will record continuously for 12 hours. Through the use of a magazine loading feature, the tape may be changed with only a 15-second lapse in recording. Microswitches mounted on the throttle cable provide an automatic start and stop for this recording system. The centrally located playback facility shown in figure 14 is available for playback on direct writing oscillograph recorders of the segment of the magnetic tape for which analysis is desired.

5. Transient Recording Facilities

Equipment to measure and record various parameters during dynamic or transient modes of operation is available at FRDC for investigation testing.

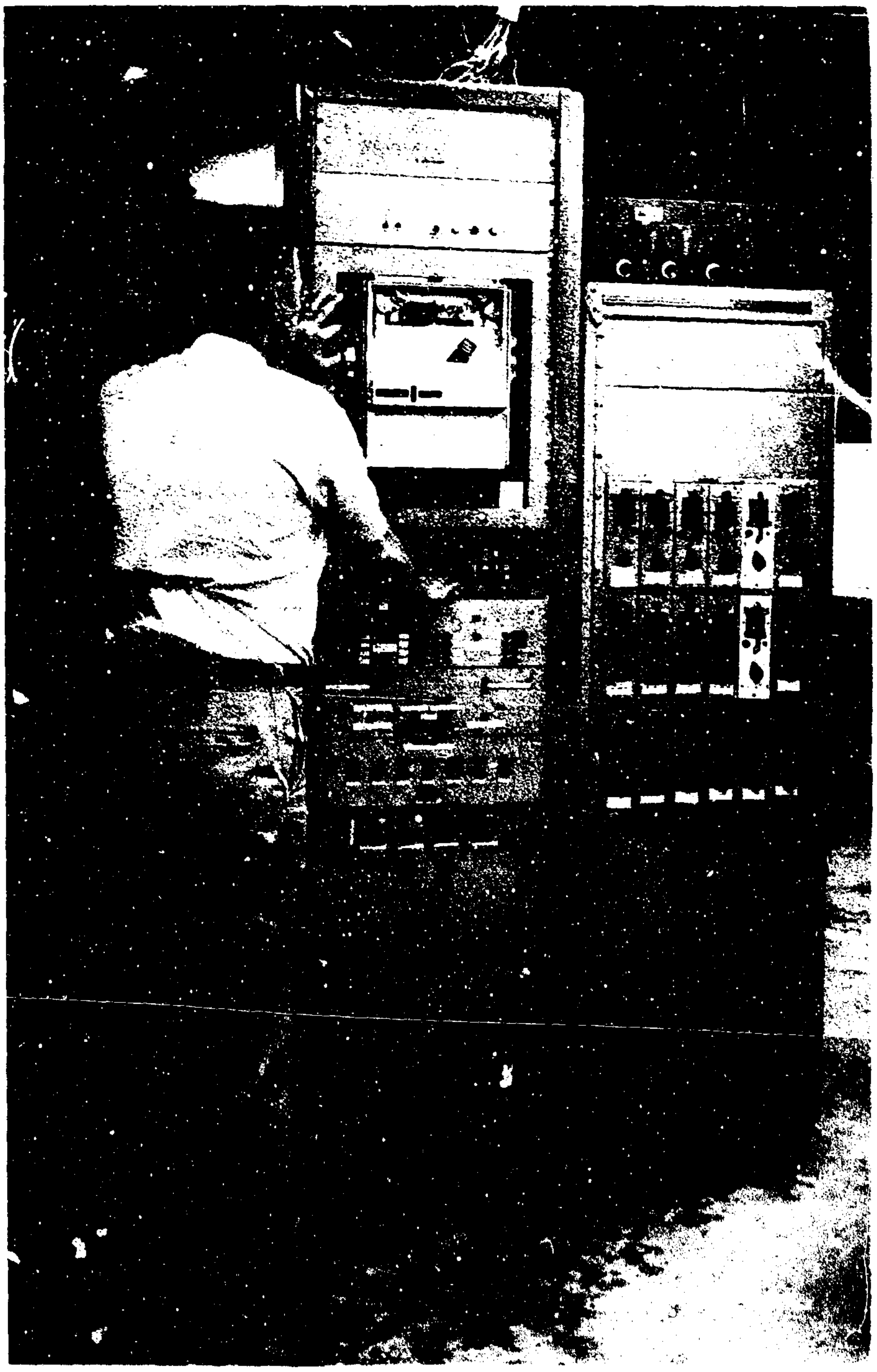


Figure 13. Continuous Data Monitoring System Record Station Used on All Engine Test Runs FC 12373 EI

Figure 14. Continuous Data Monitoring System Reproduction Station FC 12374 EI

Recordings are made on a variety of oscillographs, the particular type depending on the requirement of the test program. The majority of the transient measurement equipment is assembled in each stand from individual components in quantities dependent on the complexity of the recording program. Figure 15 shows a typical transient measurement system. Approximately 600 oscillograph channels are available.

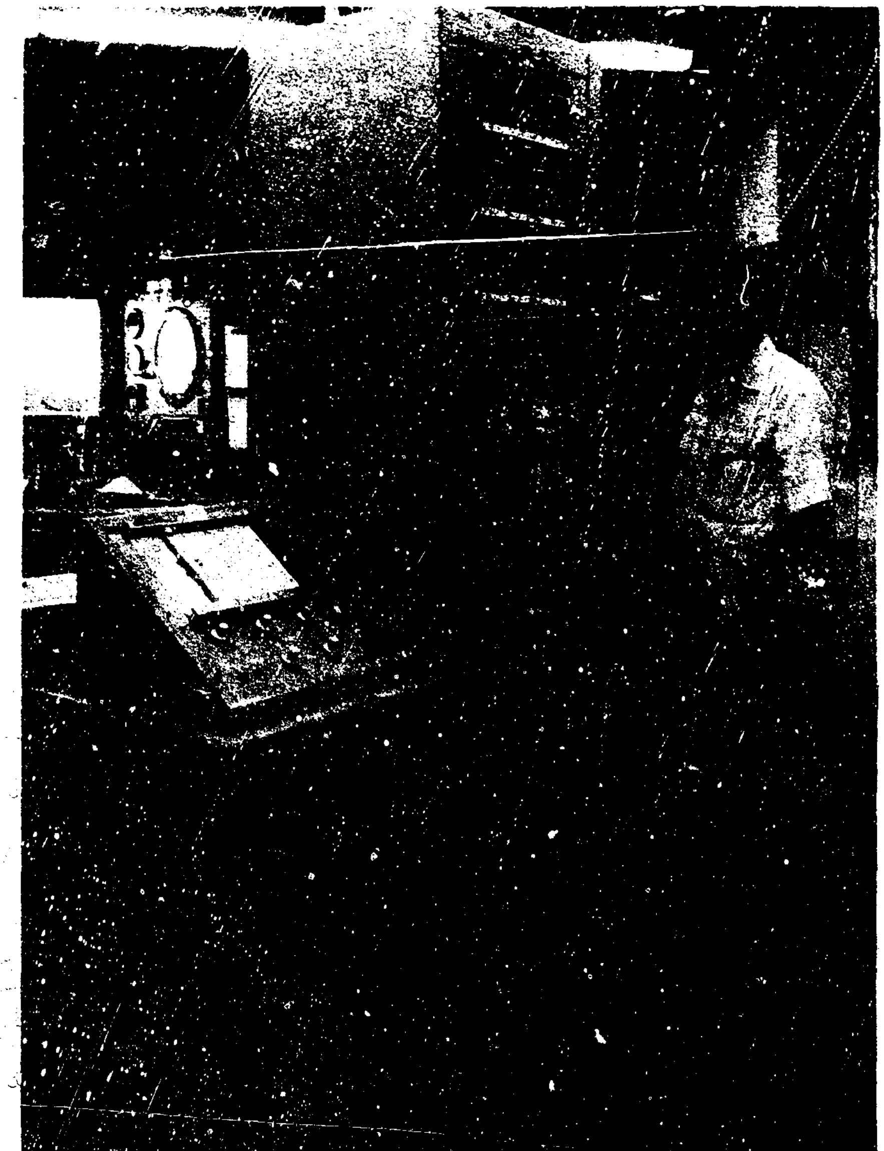


Figure 15. Oscillograph and Ratio Plotter Installation — FC 12375 EI

One of the most important operating characteristics of a turbine engine fuel control can be indicated by a graph of the ratio of fuel flow (W_f) to burner pressure (P_b) plotted vs engine rotational speed. To facilitate the production of W_f/P_b vs RPM plots on the test stand during engine operation, FRDC developed the plotter shown on the left side of figure 15. A voltage proportional to the ratio of signal amplitude from a turbine type fuel flowmeter and a strain gage bridge type pressure transducer sensing burner pressure is impressed on one axis

of an X-Y plotter. The other axis of the plotter is supplied a voltage proportional to engine rotor speed.

This equipment has greatly facilitated fuel control performance analysis by producing plotted results concurrent with engine running, thereby permitting immediate decision on any future programs.

6. Proximity Measurements

Proximity pickups that operate on a variable capacitance, variable reluctance, or eddy current principle are used to define dynamic and static motion of engine components. These pickups are required in vibration problems where the mass of conventional vibration transducers changes the inherent vibration characteristics of vibrating members, such as a small part of lightweight structure. Proximity probes have also been used to detect compressor blade flutter under engine operating conditions and to monitor the clearance between an engine wall and an internal moving part. Probes are available to measure displacement in the 50-microinch static and 1-microinch dynamic range.

7. Dynamic Analysis Equipment

Vibration, strain gage, sound, and dynamic pressure data are recorded on 14-channel one-inch magnetic tape record/reproducers. These recording systems are located in the test area control rooms and have permanent cabling to the data acquisition amplifiers located in each test stand. The data recorded on these systems are analyzed by the Dynamic Analysis Group using the equipment shown in figures 16 and 17. This group handles all FRDC data analysis requirements of turbine engine development programs.

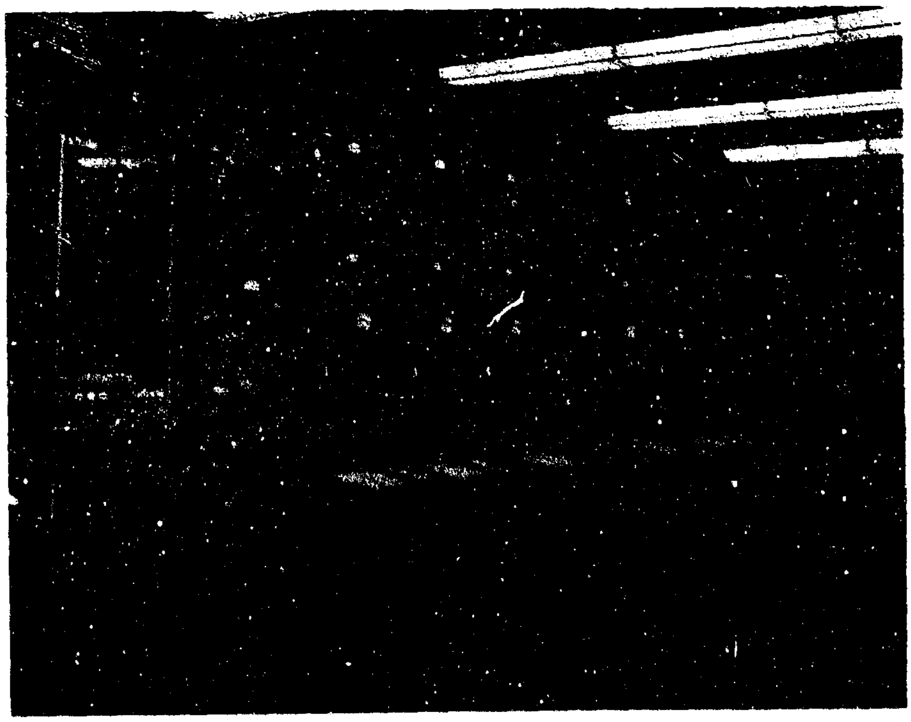


Figure 16. Multichannel Wave Analyzer (Left Side View) FC 5255 EI

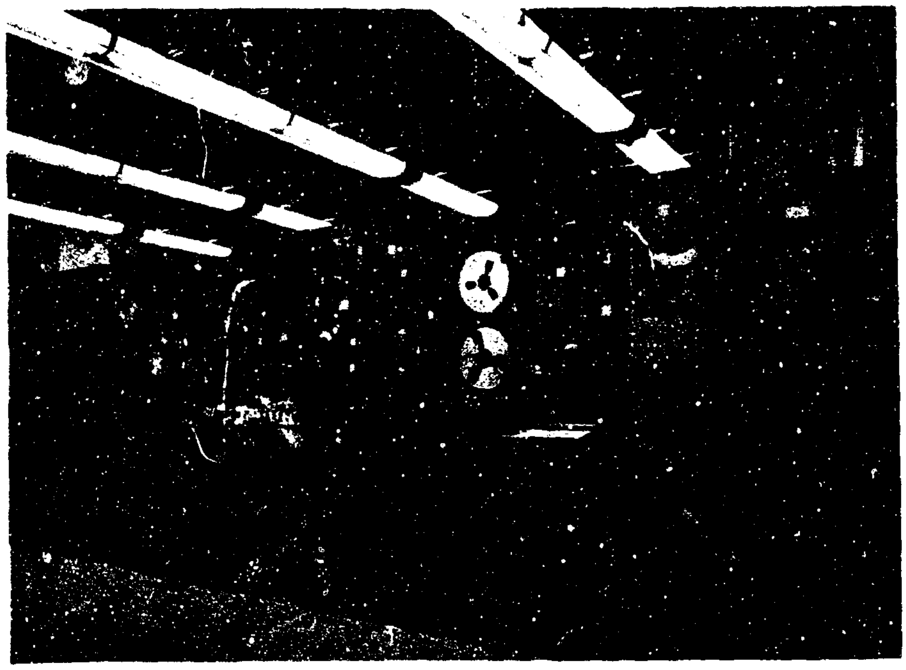


Figure 17. Multichannel Wave Analyzer (Right Side View) FC 5616 EI

The dynamic data analysis room offers the capabilities of a multi-channel wave analyzer system that can analyze sinusoidal, complex, and random waves. The system will produce graphs containing information relating amplitude versus time or speed, amplitude versus frequency or order, amplitude versus octave or third octave power spectral density cross spectral density, transfer functions, and probability functions. Plots of amplitude vs frequency are shown in figure 18. The system also contains multichannel tracking analyzers which have been used extensively during the development of the J58 engine.

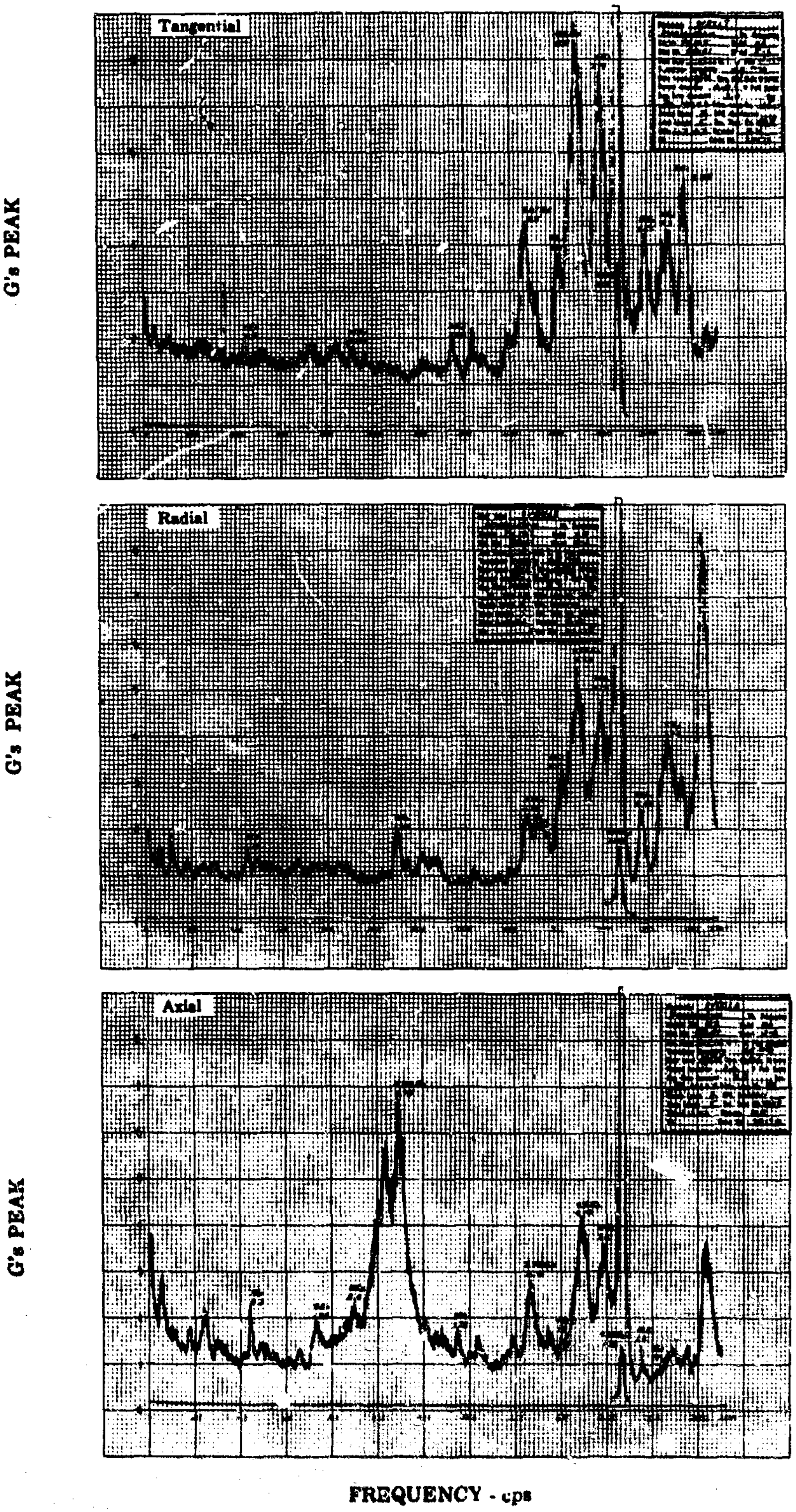


Figure 18. Linear "G" Plots of Data Recorded During Engine Firing - Three Accelerometers Located in Area of Previous Failure on Turbine Discharge Line

FD 7618
EI

8. Performance and Analytical Measurement Section

a. Liquid Flow Measurement

Engine fuel consumption is one of the most important engine parameters measured, and to ensure the utmost accuracy, a precision system has been established to determine fuel flow. The turbine type flowmeter sensor is used exclusively in determining the volumetric flow rate and has become an industry standard because of its extreme versatility, compactness, and reliability. Specific gravity of the flowing fuel is derived from pressure and temperature measurements made simultaneously with volumetric flow rate indication of the turbine meter, thus permitting conversion of volume flow to weight units.

All fuel flows directly affecting the more important performance parameters of the engine are measured redundantly, i.e., with two flowmeters in series. In addition, the flow measurement circuit is staged (two meters covering the high flows and two meters covering the low flows) to take advantage of the best operating characteristics of the meters. Wherever possible, each meter contains two pick-up coils, permitting complete versatility in the manner of detecting and displaying the meter's flow rate indication. Flow rate is displayed by both a digital counter and a frequency meter in the test stand control room while the data recording system has the ability to record flow rate in either the steady-state or the transient mode.

The redundant indication of flow rate with two meters in series ensures the validity of the flow rate indication. Constant cross checking is practiced and the flow indication of each meter must agree with the other meter in series within 0.5% for the measurement to be considered valid. Any deterioration in the performance characteristics of the meter is thus easily, and quickly, detected. Statistical use of the principle of redundancy also permits reducing the effects of many random variables (such as nonrepeatability associated with the meter, the installation, and the calibration procedure), thus producing a more accurate indication of the flow rate.

Meter accuracy is maintained at the highest level by periodic calibrations at 6-month intervals. A complete physical inspection of the meter is performed before each calibration. Each meter is individually calibrated on either or both of two calibration systems. A Cox Calibrating Stand Type 305HT, similar to the facility used by the National Bureau of Standards, is capable of producing flow rates from 200 pounds per hour (lb/hr) through 13,000 lb/hr at fuel temperatures ranging from 90°F to 300°F. Flow rates from 2000 lb/hr through 150,000 lb/hr at a fuel temperature range of 90°F through 200°F can be produced on a Fischer and Porter Master Calibration Stand.

Both of the calibration stands are correlated monthly with the National Bureau of Standards by use of transfer standards. These standards are turbine type flowmeters. Agreement with NBS is consistently maintained within ± 0.26% of point. At normal operating conditions, this system permits overall individual meter calibration accuracy within ± 0.75% of point.

b. Gas Flow Measurement

Gas flow can be measured to accuracies to ± 1% of point utilizing ASME or VDI standard orifices. Consideration is given to the configuration of both the upstream and downstream plumbing and, when necessary, the duct is traversed to assure uniform velocity and temperature profiles and acceptable small swirl angles. Measurements are also provided utilizing other head meters including nozzles, venturis, critical laminar flowmeters and variable area, thermal, and turbine meters. Data are corrected, whenever necessary, for real gas effects.

Calibration facilities at FRDC include a G. K. Porter Automatic Flow Rate Calibrator (100 to 25,000 sccm of various gases), standard orifices (0.5 to 200 scfm of air at 15 to 80 psia) and a Cox Instruments Flow Bench (0.5 to 2500 scfm of air at 15 to 235 psia). Calibrations are also purchased from the NBS and from the Colorado Engineering Equipment Station, Inc.

Flowing fluid characteristics (i.e., temperature, static and total pressure, velocity, and flow direction) are measured by traversing when fixed instrumentation is undesirable because of the blockage it presents to the flow or to the limited number of data points available.

Systems capable of traversing 22 linear-rotary positions simultaneously are available. Five data system channels are usually required per traverse position. Forty-three linear traverse systems are available to traverse probes through spans up to 25 inches. Data can be acquired continuously from these systems or the system can be traversed and data recorded in increments. Data acquisition from preselected incremented traverse positions is hastened by utilizing multiple traverse systems.

A large variety of probes for use with the above mentioned traverse systems is maintained. These probes provide the capability to measure temperatures, total and static pressures correctable to within ± 1% of velocity head up to Mach 1.3, and yaw and pitch angles within ±1 degree. Probe calibrations are provided in ambient free stream jet sizes up to 6 inches from Mach 0 to 1.0 and in a wind tunnel up to Mach 1.3. Calibrations are provided to facilitate data correction due to variations of yaw angle, pitch angle, Mach number, probe immersion, and recovery.

Fast response hot wire and hot film anemometer systems are applied to the definition of velocity profiles caused by rotating compressor blading. The systems can also be applied to the measurement of mean velocity, turbulence level, yaw angle, and the detection and definition of rotating stall.

c. Temperature Measurement

Development of gas turbine engines requires a combination of technical skills and reliable instrumentation. Accurate determination of gas and metal temperatures is an essential capability required for successful engine development.

The most conventional sensor for temperature measurements in gas engines is the thermocouple. Thermocouples are peculiarly suited to aircraft requirements in that they are accurate, rugged, versatile, small, and generally inexpensive; however, the success of the thermocouple measurement is largely contingent upon

the geometry of the probe and the calibration capabilities of the testing organization. Measurement devices in the hostile environment of the combusting gases are prone to rapid deterioration, necessitating adequate standards for early recognition of this type of failure.

Pratt & Whitney Aircraft temperature measurements are all traceable to the National Bureau of Standards. Our Interlaboratory Standards are calibrated directly by NBS, and these in turn serve as the criterion for our working standards. The reference standards are periodically resubmitted to NBS to maintain the highest integrity of our thermal measurements.

The ability of a temperature probe to sense the thermal level of a dynamic gas stream introduces the additional requirement for information on response and recovery characteristics of various probe designs. While some probe geometries yield to analytic evaluation of these characteristics, it is highly advisable to confirm the results with test equipment for actual simulation of the dynamic gas flows.

Special capabilities have been developed for the installation of fine wire thermocouples on turbine blades and vanes. Installation of 0.010-inch diameter swaged tubing with 0.003-inch diameter conductors has now become routine (figure 19). Before installation, the fine wire is checked for thermo-electric conformity to NBS. Circular No. 561 (Reference Tables for Thermocouples). All thermocouple wire is purchased against a technical specification which stipulates the ISA - Special Limits of Error. Conformity to the specification is established through the use of various pure metal freezing point standards.

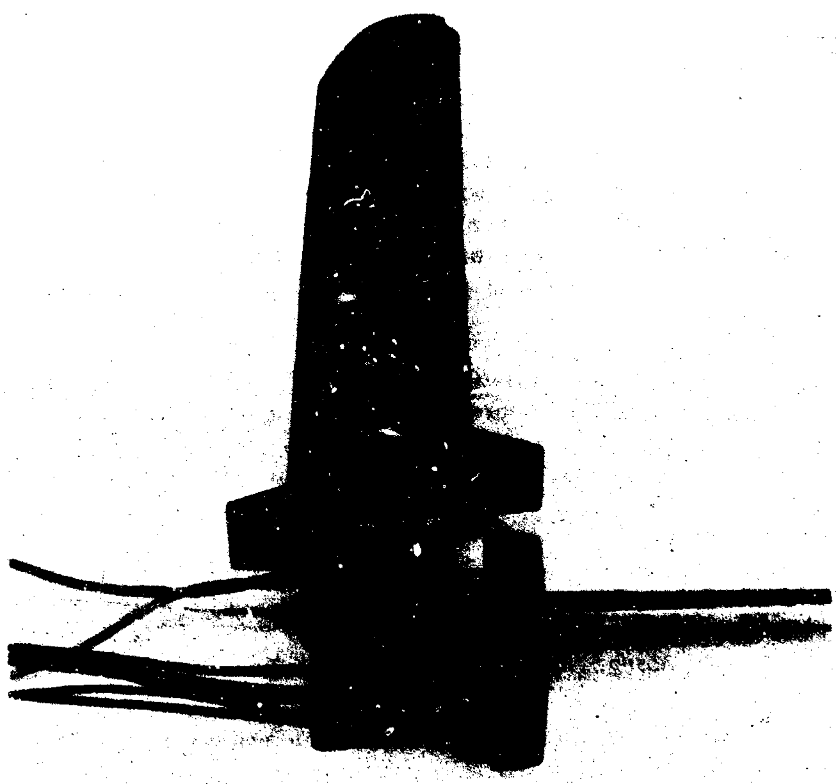
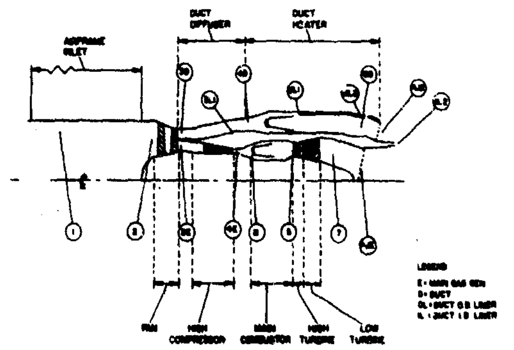


Figure 19. SST 1st-Stage Turbine Blade 0.010-Inch OD Swaged Thermocouple Instrumentation FE 55049 EI

Considerable experience has been obtained in developing techniques for temperature measurement of high velocity jet engine exhaust streams. Numerous probes have been built and intercompared to establish a confidence in our ability to determine the exhaust temperature profile of turbine engines. The problems have been severe because of the strength limitations of materials at elevated temperatures and design subtleties to minimize the corrections due to the dynamic effects of the gas.

Maximum surface temperature determinations are essential in the evaluation of the design of engine hardware. In many instances such temperatures are difficult to obtain or are not obtainable by conventional means. A development on maximum surface-temperature measurement using radioactive Kryptonates is being vigorously pursued in cooperation with the United Aircraft Research Laboratories. This method utilizes the temperature versus outgassing function of a Kryptonate for surface temperature determination. The purpose of this program is to determine the applicability of the Kryptonate method to engine hardware by Kryptonating actual engine hardware and operating the hardware in burner rigs and engines. The methodology is now well advanced and engine parts are being tested to determine operational limitations and evaluate another working tool for the JTF17 engine development.

Figure 20 summarizes the development instrumentation used in each engine station identified on the sketch showing the engine gas paths. The primary temperature instrumentation is as follows:



Station	Parameter	Inst Type	Number	Comments
	T_{t1}	[illegible] T/C's	12	[illegible] T/C's at Sea Level, [illegible] T/C's at Altitude
Inlet	P_{t2} - P_{s2}	5-Pos Pitot - Static Rake	6	[illegible] Wall [illegible] with ID and OD Wall Static Taps Required
	P_{s2}	ID and OD Wall Taps	4 ID and 4 OD	
	[illegible]*	5-Pos Kiel Rake	2	*Combination [illegible] Rake
[illegible]	[illegible]	ID and OD Wall Taps	2 ID and 2 OD	2 Used
	[illegible]**	5-Pos Rake	2	
	[illegible]**	5-Pos Kiel Rake	2	**Combination [illegible] Rake
[illegible]	[illegible]	ID and OD Wall Taps	2 ID and 4 OD	2 Used
	[illegible]*	5-Pos Rake	2	
	[illegible]	5-Pos Rake	3	
[illegible]	[illegible]	5-Pos Rake	3	
	[illegible]	5-Pos Rake	4	5 Total and Static Pressures Per Rake
	[illegible]	Wedge Type Traverse Probe	4	Provisions Have Been Made for Traversing the Duct Heater Inlet
Primary Combustor	[illegible]		2	
[illegible]	[illegible]	Vane Leading Edge	[illegible]	
	[illegible]	Vane Leading Edge T/C	120	
[illegible]	[illegible]*	[illegible] Probe	4	*[illegible] Probes
	[illegible]*	5-Pos [illegible] Rake	9	[illegible]
[illegible]	[illegible]	[illegible] Probe	[illegible]	Rakes are Water Cooled
	[illegible]	[illegible]	1	
[illegible]	[illegible]	[illegible] Rake	1	[illegible]
[illegible]	[illegible]	Kiel Probes	2	[illegible] Cooling Air Measurements
	[illegible]	Wall Taps	2	
	[illegible]	Thermocouples	3	
[illegible]	[illegible]	Kiel Probes	3	[illegible] Cooling Air Measurements
	[illegible]	Wall Taps	3	
	[illegible]	Thermocouples	3	

Note: All total pressures and temperatures are recorded at centers of equal areas.

Figure 20. JT?17 Gas Stream Instrumentation **FD 16661 EI**

1. Station 1 - Engine Inlet - The inlet screen of the bellmouth is instrumented with twelve copper-constantan thermocouples arranged at four circumferential positions in each of three planes. These twelve thermocouples are connected to give four average temperature measurements. Each average temperature hookup samples a different circumferential position in each of three planes. Special tolerance thermocouple wire and a ± 0.2°F reference oven are used to obtain the necessary accuracy.

2. Station 3 - Fan Duct Discharge and High Compressor Inlet - Two separate types of combination total temperature and total pressure rakes are used. One type of rake senses the fan duct discharge total temperature and the high compressor inlet total pressure. The other type of rake senses the fan duct discharge total pressure and the high compressor inlet total temperature. The five sensors in each gas stream are spaced at the centers of equal areas. Side-vented kiel head sensors are used to stagnate the gas stream at the chromel-alumel thermocouples. Two of each type rake are used for an engine test. (See figure 21.)

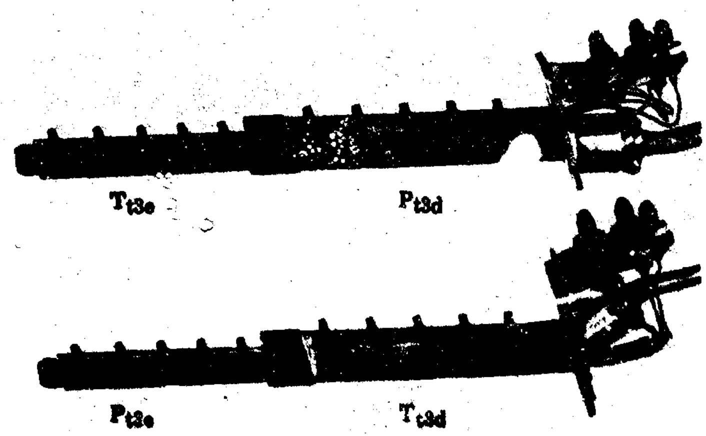


Figure 21. Station 3 Probe FD 16813
EI

3. Station 4E - High Compressor Discharge - Three total temperature rakes with five sensors each are used at the high compressor discharge. The side-vented kiel head sensors, used to stagnate the gas stream at the chromel-alumel thermocouples, are located at the centers of five equal areas. (See figure 22.)

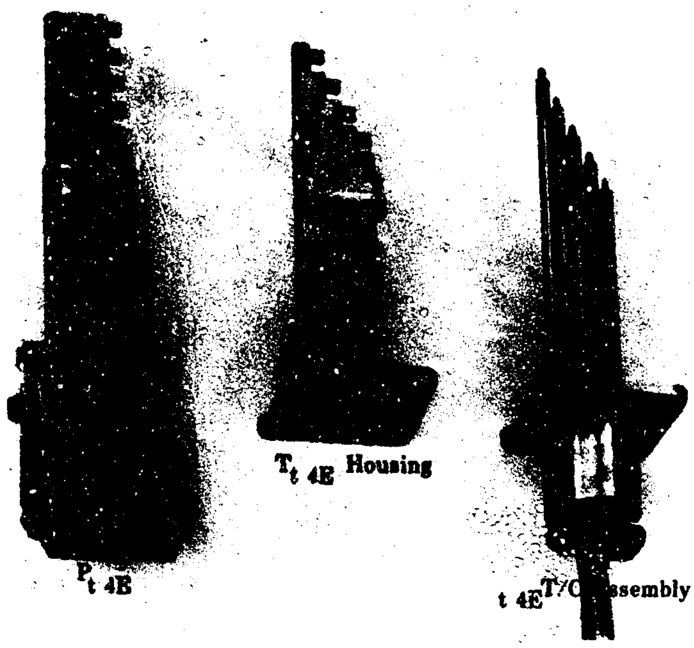


Figure 22. Station 4E Instrumentation FD 16709 EI

4. Station 5 - High Turbine Inlet - On selected development engines, 24 turbine inlet vanes are instrumented with five thermocouples each which measure metal temperature. In addition to providing profile data, these vane thermocouples allow evaluating the effectiveness of turbine cooling air through comparison with calculated gas stream temperatures.

5. Station 7 - Low Turbine Exit - Nine Exhaust Gas Temperature (EGT) probes, specified in the engine parts list, are used to measure the average total temperature. Each probe has given total temperature sensors spaced at centers of equal areas. These five thermocouples are connected in parallel to present an average temperature for the profile. These sensors stagnate the gas stream at the individual thermocouples and aspirate to a lower pressure through one discharge hole.

6. Station 8 - Duct Heater Nozzle Exit - A special water-cooled traverse probe was developed to sense simultaneously the total temperature and total pressure immediately upstream of the duct heater nozzle flaps. The noble metal thermocouple has a dual element and is designed to aspirate to a lower pressure. The gas stream is stagnated and the radiation and conduction losses are minimized through the special design. As many as eight of these traverse probes are used simultaneously on development engines to take data at the centers of ten equal areas. (See figure 23.)

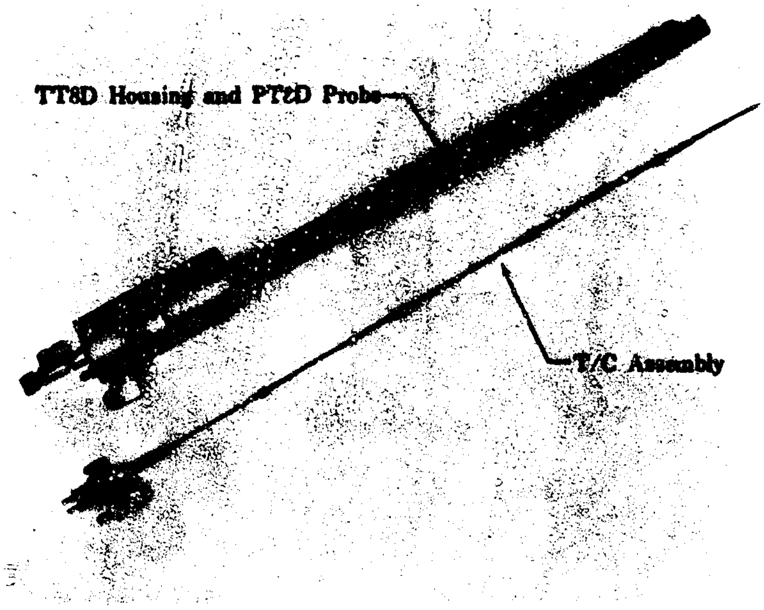


Figure 23. PT8D-TT8D Traverse Probe — FD 16636 EI

d. Pressure Measurement

Pressure measurement instrumentation and technology are established to handle a wide variety of pressure measurement problems. Supporting these are facilities for fabrication and repair, development testing, calibration, installation, data acquisition, data reduction, and data analysis.

Development engine gas path pressure probes are designed through the combined efforts of the Pressure Measurement Group, the Engine Performance Group, and the Engine Design Group to fulfill special requirements such as high temperature, minimum flow disturbance, limited space, minimum flow angle, good frequency response and minimum error. Many of these designs are extensively tested under simulated operating conditions before the final item is accepted.

(1) Pressure Probes and Rakes

In the development of an engine such as the JTF17, extensive gas path pressure measurements are required. The probes installed inside the engine are streamlined to prevent flow disturbances and to reduce blockage. The structural integrity must be equivalent to that of the engine parts to prevent possible engine damage through failure.

In supplying the numerous pressure measurements required for the evaluation of engine performance, where possible, advantage was taken of existing struts and vanes by installing the pressure instrumentation into them. In some cases rakes are used to obtain the pressure profile, while in other cases the profile is obtained by traversing the gas stream. Figure 20 summarizes the development instrumentation used at each engine station. The basic performance pressure measurements are obtained as follows:

1. Station 2 - Engine Inlet - Six rakes span the inlet, providing 42 total pressure measurements and 30 static pressure measurements. Each rake has five sets of total and static taps located at the centers of equal areas. An additional total pressure tap is provided at the ID and OD ends of the rake to facilitate boundary layer studies. This rake is a unique design necessitated by the rigid requirements noted above, plus the additional requirement that the static pressure taps be relatively insensitive to probe misalignment. This design, which was developed and tested at FRDC and tested in a subsonic wind tunnel at the United Aircraft Research Laboratory, provides the total and static pressure measurements necessary to accurately determine the total engine airflow. (See figure 24.)

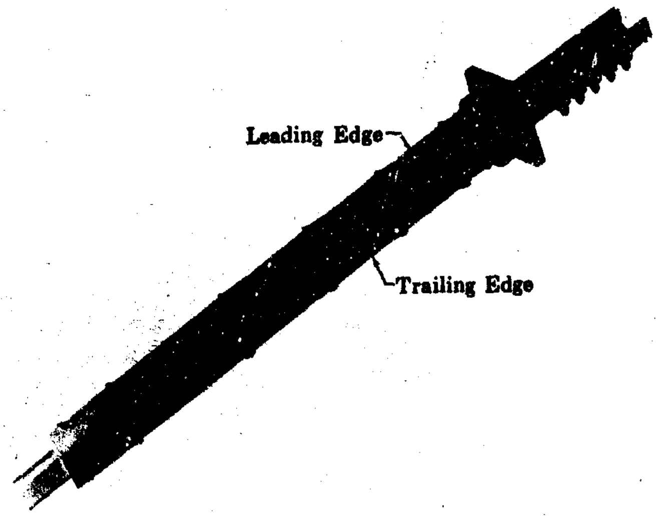


Figure 24. Station 2 Probe FD 16814 EI

2. Station 3 - Fan Duct Discharge and High Compressor Inlet - The two separate types of rakes used were partially described under Paragraph C.1, Station 3 Temperature Measurements. These rakes have five side-vented kiel head sensors located at the centers of equal areas in both the fan duct and the high compressor inlet section. (See figure 21.)

3. Station 4D - Duct Heater Inlet - The Station 2 design concept was used for the four rakes located at the duct heater inlet. Each rake has five total and five static sensors spaced at the centers of equal areas for profile determination and for airflow calculations. (See figure 25.)

4. Station 4E - High Compressor Discharge - Three rakes with five total pressure taps located at the centers of equal areas are used to provide pressure profile data at the high compressor discharge. These rakes use side-vented kiel head sensors to stagnate the gas stream. (See figure 22.)

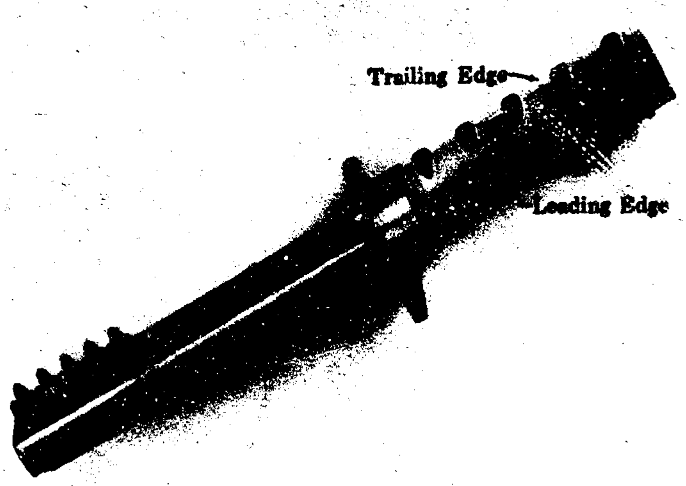


Figure 25. Station 4D Probe

FD 16815
EI

5. Station 5 - High Turbine Inlet - On selected development engines four inlet guide vanes are instrumented with five kiel head total pressure sensors each. These sensors are spaced across the flow annulus to provide profile data.

6. Station 7 - Low Turbine Exit - Four Engine Pressure Ratio (EPR) total pressure rakes, specified in the engine parts list, are used to measure the average turbine discharge pressure. Each rake has eight sensors which are spaced across the annulus and are manifolded internally to present an average total pressure for the profile.

7. Station 8 - Duct Heater Nozzle Exit - Special water-cooled traverse probes are used to determine the total pressure profile at the duct nozzle exit. The uncooled tip of the pressure sensor is made of a noble metal to withstand the high temperatures associated with maximum duct heating. (See figure 23.)

8. Station 9 - Gas Generator Nozzle Exit - The total pressure profile at the exit of the gas generator nozzle is measured by a 20-position, water-cooled pressure rake. Figure 26 shows the rake installed on a JTF17 engine. The 20 sensors are located at the centers of 10 equal areas. The support for this rake was designed with provisions for rotating the rake to obtain a complete pressure profile.

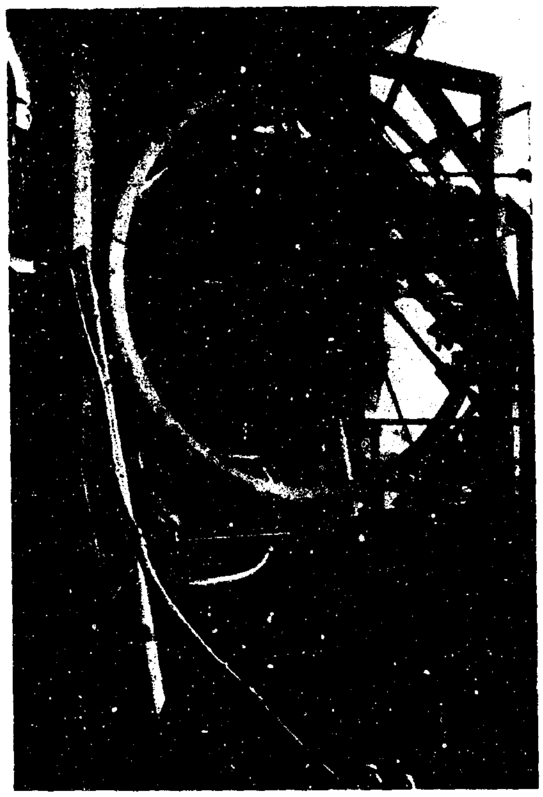


Figure 26. Water-Cooled Pressure Rake Installed on JTF17 Engine FD 16635 EI

During the early Phase II-C model and rig testing of the JTF17 program miniature boundary layer rakes and inlet pressure rakes were designed, fabricated and tested at FRDC. This instrumentation was used to determine boundary layer profiles and inlet distortion, yielding the information required for design decisions.

Facilities and laboratory equipment are available for determining pressure system (probe, tubing, etc.) frequency response and time constant. Pressure systems must be designed with some knowledge of the source pressure behavior and the required system response. Design testing of the JTF17 pressure measurement instrumentation was performed in cases where system response was of interest.

(2) Pressure Transducers

(a) Static (Low Frequency, Below 100 cps)

There are in excess of 3000 strain gage type pressure transducers at FRDC in ranges from 1 to 10,000 psi. Designs are presently available for water-cooled transducer housings that can be used to cool these transducers when they are required to operate in a high environmental temperature.

(b) Dynamic (High Frequency)

Although these transducers are usable down to frequencies below 1 cps they are generally used where pressure fluctuation is expected to be 20 cps and

greater. Under ideal conditions, there is negligible reduction of accuracy up to 20,000 cps. Pressures from less than 1 psi to 10,000 psi can be measured with various models of these transducers.

Dynamic pressure measurements have been made on duct heater sectors, the full-scale JTF17 duct heater rig, and the experimental JTF17 engine. Transducers that are virtually insensitive to vibration are now being used with ver en-couraging results.

Compressor rotating stall has been successfully detected and identified on both a turbojet compressor rig and a single stage test compressor. With the proper arrangement of transducers, it is possible to determine the number of stall zones, the stall zone rotating speed, and the size and shape of stall zone.

Four dynamic pressure transducers have been installed in a JTF17 experimental engine duct to determine the pressure amplitude of fan blade passing frequencies present in the fan duct. (The environmental conditions at these locations prohibit the use of conventional microphones.) This information is being used to design a sound absorption configuration into the prototype engine.

Frequently, dynamic pressures are measured in hydraulic systems to determine control system component instability, effectiveness of hydraulic pump piston frequency absorption devices, and presence of cavitation. If necessary, fuel or water-cooled transducer adaptors can be used in high temperature environments such as frequently exist in locations where hydraulic pressure measurements are required.

e. Thrust Measurements

The Thrust Measurement Group provides engineering coverage in the specialized field of force measurement. The group maintains and calibrates laboratory and test equipment, supervises installation of test equipment, monitors tests and data acquisition, and analyzes results as required. Responsibilities for use and maintenance of force standards include establishing procedures, data analysis, initial test bed design, installation and checkout, and providing traceability to the National Bureau of Standards.

The calibration standards maintained for force measurements are Morehouse Proving Rings, which are periodically returned to NBS to maintain certification. Traceability from NBS to the test stand measurement load cells is maintained through Force Calibrators and Weigh Kits.

9. Electronics Section

a. Electronics Design

Technical capabilities exist for the design and development of instruments and systems used in obtaining and/or analyzing engine or component test data. Even though some instruments and systems are available commercially, time and money can frequently be saved by in-house design and development effort.

Specific examples of recently completed electronics design projects are:

1. An automatic trim motor control system was designed and developed for automatic operation of the J58 fuel control trim motor. This system generates a desired exhaust gas temperature analog and compares it to the actual measured EGT. The error signal is used to control the trim motor. The system schedules three different rates of trim depending on amplitude and direction of error signal.

2. A highly compact, 12-channel strain gage translator/amplifier/power supply system was designed and developed. Space requirements were reduced to approximately one-tenth of presently available systems through the use of modular solid state power supplies, amplifiers, and calibration circuits. Each channel was designed with an independent bridge power supply, completion network, and amplifier for maximum isolation and reliability.

3. A pressure transducer data recording system and a playback system were designed and developed for a J58 engine face distortion program. Capability of recording, on FM magnetic tape, 48 data channels including time correlation and event markers was provided under a stringent requirement of using a minimum of equipment space. Highly compact solid state modules were designed for signal conditioning and both local and remote control functions, and portable, solid state tape transports were used for recording. A separate system was developed to condition all data and time correlation signals to facilitate digitizing the FM magnetic tapes using a digital data recording system during playback. The digital tapes were then processed through the IBM laboratory to provide calculated data for ram recovery and distortion factor.

4. A dual linear-traverse control was designed and developed for semi-automatic control of two linear actuators. The unit incorporates the following features:

   a. A solid state circuit breaker with an adjustable trip point to disconnect actuator power in case of mechanical overload

   b. A high speed bi-directional, electromechanical counter with transistorized logic and drive circuitry for accurate indication of probe position

   c. Plug-in printed circuit cards for overload out and counter drive circuits

   d. An ammeter to monitor the actuator motor current

   e. Remote actuator drive control automatic programed traversing

   f. Simplified single switch control for actuator drive and direction.

b. Electronics Applications

Technical capabilities are available for the modification of existing instruments, either commercial or P&WA made, to meet new or changed test instrumentation requirements and the construction of new instruments to meet immediate needs. In most cases, either the entire instrument or a major porti of the instrument must be designed and built at Pratt & Whitney Aircraft.

Some typical products or systems up n which considerable modification or design has been performed for turbojet evelopment programs are:

1. BCD-to-decimal decoder and display system for photorecorder
2. Data commutation unit for use with wave analyzer
3. Remote sound monitor system
4. Vibration data monitor with plug-in filters
5. Low-frequency galvanometer-driving charge amplifier
6. Charge amplifier with adjustable level sense circuits
7. Vibration data recording system for vibration exciters
8. Four-channel filtered integrator with meter readout
9. Instrumentation system for heat transfer test rig
10. Jet engine fuel pressure monitor
11. Wide band screech meter
12. Mobile transient recording system.

c. Instrument Laboratory Service

Within the Electronics Section is the capability of providing technical coverage of instrument laboratory electronic systems and equipment, radio frequency interference tests, and the electrical standards laboratory.

(1) Instrument Laboratory Electronic Systems and Equipment

Evaluation tests are performed to provide a sound basis for new instrument selection and purchase.

Acceptance tests are performed on newly purchased equipment to assure compliance to purchasing specifications. Technical liaison is established with the instrument manufacturer when an instrument is not adequate in performance.

Engineering decisions are established for difficult instrument repair problems. Technical liaison with the instrument manufacturer is performed when necessary.

A computer program has been provided for comprehensive instrumentation calibration records. Time intervals between calibrations are then adjusted on the basis of instrument accuracy and calibration cost. With this program, many thousands of dollars of calibration costs are saved annually. In addition, assurance is obtained that high quality instrument performance is being delivered to the test program.

(2) Radio Frequency Interference Qualification Tests

RFI tests assure that the radio frequency noise generated by electrical components on propulsion systems and components are within safe established limits. Tests of this type are conducted in a 20 ft x 10 ft x 10 ft shielded environment or 20 ft x 20 ft x 30 ft screen room certified under Mil-STD-285.

d. Electrical Standards Laboratory

To ensure the accuracy of data obtained in various testing programs, an Electrical Standards Laboratory is maintained with primary and secondary standards traceable to the National Bureau of Standards. To supplement the certified standards, the laboratory has 144 traceable secondary standards including frequency standards, potentiometers, bridges, voltage dividers, resistors, capacitors, AC and DC precision calibrators, impedance bridges, and precision voltmeters. Maintenance and calibration techniques for electrical standards are established by the Laboratory Service Group.

e. Stand Systems

Capabilities for design, modification, checkout, and maintenance of open-loop and closed-loop facility and test stand control systems and certain special test stand instrumentation are available in the Electronics Section.

Forty-channel, digital sequencers capable of scheduling test stand and rig control operations with millisecond precision have been designed, installed, and put into operation. lid state analog computers have been designed and installed to provide both linear and non-linear control of flows, pressures, speeds, etc.

Specific test stand control systems have been: simulation of jet engine characteristics to control the speed of a test stand drive motor, representing the jet engine speed limiter to monitor N1 and provide fuel solenoid shutoff on overspeed; closed loop control of nozzle position as a function of speed error on jet engine tests; closed loop control of high speed. high pressure, gas turbine driven pumps; and automatic position control of traverse actuators for temperature and pressure profile studies of jet engine combustors.

10. Data Recording Section

The Data Recording Section function is to support the engine development effort directly at the test facility. For that reason the description of this activity is covered in Volume V, Report B, (Facilities Program).

Proper interpretation of test measurements is a necessary ingredient in the design evaluation process. Liaison with Project Engineering and Performance Analysis Groups to assure proper interpretation with regard to measurement accuracy, response, and data processing methods is the primary responsibility of the Data Validity Group.

Specific group functions permitting fulfillment of this responsibility are (1) dissemination of information on measurement systems and their related hierarchies of calibration equipment, (2) statistical analysis of measurement systems to provide measurement accuracy statements, (3) formulation and standardization of mathematical techniques applied to recorded test data to produce

maximum yield from measurement calibrations, (4) coordination with the Computing Laboratory on data processing techniques applied to test and calibration data recorded on the automatic digital data acquisition systems, and (5) surveillance of test data to assure optimum performance of measurement systems.

11. Standards

A well integrated calibration system is actively maintained which ensures maintenance of accuracy, traceable to the National Bureau of Standards, for all instruments and/or data acquisition systems. This calibration system meets or exceeds all the requirements of Section 9, "Inspection, Measuring, and Test Equipment," of NASA Quality Publication 200-2, 3/1/62, Section 4.1, "Measuring and Testing Equipment," of Mil-Q-9858A, 12/16/63, and military specification, "Calibration System Requirements," Mil-C-45662A, 2/9/62.

The instrumentation technology and accuracy of the measurement of performance parameters is sufficiently understood and applied to meet the standard instrumentation requirements for the JTF17A-21 development program. The experience level of the Instrument Engineering staff is sufficient to meet any special instrumentation requirements that should occur in the development program.

F. TEST FACILITIES

1. Definition of Effort

Facility Engineering provides the necessary test facilities required to meet test requirements outlined in Phase III of the SST program. A complete description of the facilities utilized in Phase III is contained in Volume V, Report B. Responsibiliites of Facility Engineering are as indicated below:

1. Facilities Engineering have under their cognizance a Facilities Design Engineering Group responsible for all P&WA facility designs, and for the development of all design criteria for dissemation to architectural engineering firms.

2. Once the design of a facility is established, it is the responsibility of Facility Engineering to initiate procurement through a Materials Control Group, utilizing Government Reserve Equipment Screening where available.

3. Installation of all special test equipment is accomplished by separate purchase order to an installation contractor, under the direction of the responsible Facility Engineer.

4. Checkout and inspection of all special test equipment is under the supervision of Facility Engineering during the final phase of construction, in coordination with the Inspection and Test Operation Departments.

2. Phase III Test Stands

The test stands utilized in Phase III of the SST program are as follows:

a. Sea Level Engine Calibration and Endurance Test Facilities

A total of four sea level test stands are planned to conduct the JTF17 engine development program. Three existing FRDC stands will be available and capable, with modifications, of testing the JTF17 engine; A-3, A-4, and A-5. One new stand, A-9, will be built.

(1) A-3 and A-4 Test Stands (Available)

General Description - Sea level calibration and endurance testing of full-scale engines is accomplished on A-3 and A-4. Each stand consists of engine mount and thrust measuring system, fuel supply system, and a control room provided with engine monitoring and controls. Performance data is collected through a data recording system. The stands have already been modified for JTF17 testing as part of the Phase II-C program.

Test Capabilities include thrust block, thrust stand, and measuring system capable of 80,000 pounds thrust.

Instrumentation: Centrally located data recording system and processing equipment with test stand playback, as described in the Facilities Section of Volume V, Report B with:

300 Steady-state pressure channels
40 Transient pressure and thrust channels
160 Temperature channels
10 Flow and speed channels
12 Vibration channels.

Data system produces computed performance parameters in the Control Room while testing is in progress. Most of the above channels are also reproduced in the Control Room for test personnel observation. Continuous monitoring equipment (Reference Paragraph E.4 of Instrumentation) of 11 channels fed into a magnetic tape recorder/reproducer system consisting of:

3 Pressure channels
1 Temperature channels
1 Vibration channel
3 Flow speed channels
3 Position channels

Three separate fuel systems, each capable of supplying 120,000 pounds per hour of jet fuel at ambient temperature at pressures up to 100 psig

Compressed air system capable of delivering air at a rate of 6 pounds per second at 80 psig for engine starting.

(2) A-5 Test Stand

General Description - A-5 is a sea level calibration and endurance stand for full-scale engine testing.

Test Capabilities - Same as A-3 and A-4.

(3) A-9 Test Stand

General Description - A-9 will be a sea level noise stand also suitable for testing the thrust reversers of the JTF17 engine. It will be used for engine noise level determination, utilizing truck mounted sound equipment operating on a road parallel to the axis of the engine. The stand will consist of a control room, engine thrust stand and mounts, engine monitoring instrumentation, fuel and starter air systems, and sound measuring instrumentation.

Test capabilities include thrust block, thrust stand and measuring system capable of 80,000 pounds forward thrust and 80,000 pounds rearward thrust.

Instrumentation - Control Room instrumentation for observation of pressure, temperature and flow. (Manometer, pressure gages, digital readouts and potentiometers.)

Continuous monitoring equipment of 11 channels fed into a magnetic tape recorder/reproducer system consisting of:

3 Pressure channels
1 Temperature channel
1 Vibration channel
3 Flow speed channels
3 Position channels

Three separate fuel systems, each capable of supplying 120,000 pounds per hour of jet fuel at ambient temperature and pressures up to 100 psig

Compressed air system capable of delivering air at a rate of 6 pounds per second at 80 psig for engine starting and monitoring

Three separate fuel systems, each capable of supplying 120,000 pounds per hour of jet fuel at ambient temperature and pressures to 100 psig

Compressed air system capable of delivering air at a rate of 6 pounds per second at 80 psig for engine starting and monitoring.

b. Heated Inlet Engine Calibration and Endurance Test Facilities

(1) SST Program Requirements

Three new heated inlet test stands will be utilized primarily for engine endurance testing at Mach 2.7 conditions. These stands will be designated C-8, C-9, and C-10.

(2) General Description

The stands will be interconnected to the service facilities so that any two stands may be operated simultaneously. The pressure and temperature of the air supplied to the engine will simulate that required at Mach 2.7 conditions. Fan air discharge, because of its higher total pressure, will be discharged to atmosphere. Engine air will be ducted to exhausters, which exhaust the air to atmosphere. The engine will be enclosed in an insulated shroud, and a fuel system provided to simulate actual temperature conditions encountered in flight.

(3) Data System

An independent data system will be provided to make the following measurements from C-8, C-9, and C-10 test stands:

80 Steady-state pressure channels
40 Transient pressure and thrust channels
100 Temperature channels
10 Flow and speed channels.

The system will record from one test stand at a time, but will be able to switch from one stand to another in a matter of seconds. Included is a tie-in to the existing computer in Area A providing Control Room display of critical performance parameters while testing is in progress.

(4) Test Capabilities

Fuel flow of 70,000 pounds per hour at 55 psig heated to 300°F or 120,000 pounds per hour at ambient (sea level).

Airflow: Ram - 515 pounds per second at 51 in. HgA
Airflow: Exhaust - 123 pounds per second at 10 in. HgA
Air temperature: Temperatures up to 500°F.

c. Simulated Altitude and Mach Number Engine Test Facilities

A total of three Simulated Altitude - Mach Number Engine Test Facilities are necessary to conduct the testing required for the JTF17 engine test program. In either facility, flight conditions can be simulated over the engine flight envelope. At FRDC one existing test stand, C-4, is available; one new test stand, C-6, will be constructed. An existing stand, X-210, at the Willgoos Laboratory will be modified to test the JTF17 engine. The subsonic portion of the engine operating envelope can be simulated in this stand. Heated inlet capabilities up to Mach No. 3.0 is also available.

(1) C-4 Test Stand (Available)

General Description - C-4 provides simulated Mach number conditions or pressure, temperature and air-weight flow for full-scale engine testing.

Stand Capabilities - Fuel flow of 150,000 pounds per hour at 55 psig and 300°F heated conditions.

Airflow: Ram - 1240 pounds per second at 623°F and 105 in. HgA
Atmospheric intake

Airflow: Exhaust - 300 pounds per second at 12 in. HgA
625 pounds per second at 22 in. HgA

Data Recording System: 320 steady-state pressure channel
180 temperature channels
40 transient pressure channels
10 flow and speed channels

Control Room display of computed performance parameters during test. Control Room instrumentation consisting basically of pressure, temperature, flow and speed readouts, strain gage and failure monitoring equipment as required for the development program.

(2) C-6 Test Stand

General Description - Same as C-4 stand.

Stand Capabilities - Same as C-4 stand.

(3) Engine Altitude Test Stand, X-210

This test stand, which is located at Andrew Willgoos Turbine Laboratory, is a duct-connected engine test stand. This stand is capable of operating the JTF17 engine over the subsonic portion of the flight envelope of intact down to minus 10°F. Heated inlet capability up to Mach 3 is also available.

Stand Capabilities

Maximum Altitude: 90,000 feet
Maximum Refrigerated Air: 450 pps at -10°F
Fuel Supply Capability: 60,000 pph from -65 to +165°F.

d. Simulated Altitude and Mach Number Component Test Facilities

Two full-scale fan and compressor test stands are necessary for the JTF17 development program. Each will be capable of testing single-stage, multistage and complete compressor units over a wide range of simulated altitude and Mach number conditions. One existing test stand, C-3, is available. An additional stand, C-7, will be constructed.

(1) C-3 Stand (Available)

This test stand provides simulated Mach number conditions of pressure, temperature and air-weight flow for high pressure compressor testing.

Stand Capabilities

Airflow: Ram - 400 pounds per second at 105 in. HgA
500 pounds per second at 60 in. HgA
Throttled atmospheric intake

Airflow: Exhaust - 20 pounds per second at 1.5 in. HgA
250 pounds per second at 22 in. HgA
Atmospheric exhaust

Air Temperature: 250 pounds per second at 700°F.

Steam turbine drive, delivering 24,000 hp at 8500 rpm to test compressor.

Instrumentation

Centrally located Automatic Data Recording and Processing equipment with:

180 temperature channels
200 steady-state pressure channels
40 transient pressure channels and nine speed or flow channels

Data system produces computed performance parameters in the control room while testing is in process.

Similar channels to the above are also reproduced in the control room for test personnel observation.

(2) C-7 Stand

This stand will provide simulated Mach number conditions of pressure, temperature and air-weight flow for full-scale fan or high pressure compressor testing.

Stand Capabilities

Airflow: Ram - 400 pounds per second at 120 in. HgA
500 pounds per second at 60 in. HgA
Throttled atmospheric intake

Airflow: Exhaust - 20 pounds per second at 1.5 in. HgA
250 pounds per second at 23 in. HgA
Atmospheric exhaust

Air Temperature: 700°F at 250 pounds per second at 120 in. HgA

Gas Turbine Drive: Delivering 52,500 hp at 9000 rpm

Data Recording System:

160 steady-state pressure channels
100 temperature channels
100 transient pressure channels (40 convertible to temperature)
9 flow and speed channels

Control room instrumentation consisting basically of pressure, temperature speed readouts, strain gage equipment, all sufficient to monitor development programs.

e. Turbine Rig Test Stands (Available)

Two test stands are available for turbine component testing for the JTF17 program. These stands are used to investigate and develop turbine blade and vane cooling configurations.

(1) Stand Description and Capabilities

C-1 and C-2 each provide simulated operating conditions of temperature, pressure and air-weight flow for turbine blade and vane testing.

(2) Stand Capabilities

Airflow: Ram - 8 pounds per second at 63 in. HgA
100 pounds per second at 120 in. HgA
24 pounds per second at 180 in. HgA

Airflow: Exhaust - 15 pounds per second at 4.2 in. HgA

Air Temperatures:

20 pounds per second at 900°F nonvitiated
120 pounds per second at 350°F nonvitiated
20 pounds per second at 2000°F vitiated

Jet Fuel:

5000 pounds per hour at ambient temperature to 500°F and 500 psig.

Instrumentation:

30 - 100 in. manometers tubes
43 - temperature channels (0-2400°F)
47 - temperature channels (0-1200°F)

Data Recording:

80 temperature channels
40 pressure channels
5000 measurements per second

f. Small Components Facilities

Twenty-five small component stands and benches will be used for the JTF17 test program. They will be used in testing complete control systems and subcomponents, ignition systems and such mechanical components as oil pumps, gearboxes, bearing and seal systems and other engine auxiliary equipment.

(1) D-1 Stand (Available)

General Description - This stand is for testing bearing compartment seals of various types.

Stand Capabilities

Drive: (1) Gasoline engine, 125 hp, with gearbox output speed variable to 11,000 rpm maximum

(2) "Varidrive" (15 hp), one output pad speed range 1100 to 5500 rpm, the other, 2400 to 12,000 rpm

Oil System: 22 gpm at 100 psi, design temperature 1000°F max

High Temperature Air: 1000°F at 375 psi, or 1500°F at 150 psi, 0.33 lb per second.

Altitude Exhaust: 0.3 lb per second airflow at 2 inches mercury absolute.

(2) D-3 Stand (Available)

General Description - This stand is for testing engine oil pumps and bearing rigs.

Stand Capabilities

Drive: (1) "Varidrive", 60 hp; output drive speed range 2350 to 11,600 rpm

(2) Two "Varidrives", 7-1/2 hp, 1000 to 5000 rpm variable speed output

Oil System: 22 gpm at 100 psi; design temperature 1000°F max.

High Temperature Air System: 1000°F at 375 psi or 1500°F at 150 psi, 0.33 lb per second.

(3) D-4 Stand (Available)

General Description - This stand is for testing bearing compartment seal rigs.

Stand Capabilities

Drive: Gasoline engine, 125 hp, with gearbox output speed variable to 11,000 rpm maximum.

Oil System: 22 gpm at 100 psi, design temperature 1000°F max

High Temperature Air: 1000°F at 375 psi, or 1500°F at 150 psi; 0.33 lb per second.

Altitude Exhaust: 0.3 lb per second airflow at 2 inches mercurcy absolute.

(4) D-9 Stand (Available)

General Description - This stand is a low flow static fuel test bench for testing valves, filters, spray manifolds, etc.

Stand Capabilities

Fuel Supply: 40,000 lb per hour at 1000 psi and 150°F maximum, open or closed loop.

(5) D-13 Stand (Available)

General Description - This stand incorporates hydraulic circuits and an actuator loading device for testing exhaust nozzle control systems.

Stand Capabilities

Fuel Supply: 50 gpm at 3000 psi and 100°F.

(6) D-14 Stand (Available)

General Description - This stand is for calibrating high flow fuel flowmeters, and is of the stand-pipe type.

Stand Capabilities

Fuel Supply: 200,000 lb per hour, 100° to 200°F temperature.

(7) D-15 Stand (Available)

General Description - This stand is for calibrating low flow fuel and oil flowmeters, and is of the weigh-scale type.

Stand Capabilities

Fuel Supply: 30 to 12,000 lb per hour, 100° to 350°F temperature.

(8) D-17 Stand (Available)

General Description - This stand is for testing hydraulic actuators and starter bleed valves.

Stand Capabilities

Fuel Supply: 10 gpm at 0 to 5000 psi and 150°F maximum from a variable volume pump

Air Supply: 1.5 lb per second at 1200°F and 375 psi.

(9) D-20 Stand (Available)

General Description - This stand is a turbo-fuel pump and control stand.

Stand Capabilities

Fuel Supply: 120,000 lb per hour at 1000 psi and 100°F

Air Supply: 4.2 lb per second at 375 psi and 400°F maximum

(10) D-23 Stand (Available)

General Description - This stand is for testing fuel-oil heat exchangers and other lubrication system components.

Stand Capabilities

Heat Transfer Fluid System: 8,000,000 Btu per hour capacity at 720°F.

(11) D-23A Stand (Available)

General Description - This stand is used for testing of small bearing rigs utilizing a high temperature oil system in conjunction with portable low horsepower variable speed drives.

Stand Capabilities

Heat Transfer Fluid System: 8,000,000 Btu per hour capacity.

(12) D-31 Stand (Available)

General Description - The purpose of this stand is to test gearboxes and drive systems at room temperature, under load.

Stand Capabilities

Drive: 350 hp dc drive, variable speed. Several gearboxes available.

(13) D-32 Stand (Available)

General Description - This facility is an ignition system test stand for simulated engine operation of both chemical and electrical ignition systems.

Stand Capabilities

Air Supply: Two 75 hp centrifugal blowers furnish 15 lb per second of air at 2 psig

Fuel System: 1000 gallon supply tank

Electric Power: 28 volt dc and 110 volts, 400 cycle ac

(14) DM-42 Stand (Available)

General Description - This stand is for calibrating individual fuel spray nozzles.

Stand Capabilities

Fuel Supply: 4000 lb per hour of 1000 psi and 80°F

Spray Chamber: Viewing port with adjustable protractor.

(15) DM-49 Stand (Available)

General Description - This stand is for testing starter bleed valves at room temperature.

Stand Capabilities - Air supply 2 lb per second at 125°F and 125 psi.

(16) Electronic Stand (Available)

General Description - This stand is for use in calibrating, reprograming and maintaining electronic EPR controls.

Stand Capabilities

Electric Power: 3-phase 400 cycle 208/115 volt, single-phase 110-volt 60 cycle, and 28 volt dc

Input Simulators and Load Simulators: Potentiometers and millivolt sources to simulate operating parameter input and loads

Electronic Test Equipment: Digital equipment to perform computer programing, test equipment for general troubleshooting and interconnecting harnesses and plumbing.

(17) D-7 Stand (Available)

General Description - This stand is a high temperature fuel system test stand for testing fuel pumps and controls, complete systems, system response, and heat rejection.

Stand Capabilities

Drive: 400 hp dc motor, regulated variable speed through operating range of full-scale engine rig.

Fuel System Supply: 350 gpm at 60 psi and 300°F, 15 gpm at 650°F open loop system.

Fuel System Capacity: 350 gpm at 1000 psi and 350°F test pump discharge.

Air Supply: 8.4 pounds per second at 110 psi up to 1100°F.

Heat Transfer Fluid: 750°F, 500,000 Btu per hour.

Test Chamber: Available in several configurations to test components or systems in an inert atmosphere at temperatures from 400° to 1200°F.

(18) D-10 Stand

General Description - This stand is a test bench for testing fuel system components and air turbine-driven pumps and controls.

Stand Capabilities

Fuel Supply: 100,000 pounds per hour at 1000 psi and 150°F maximum, either open or closed loop, with either clean or contaminated fuel

Air Supply: 8.4 pounds per second at 110 psi and 400°F.

(19) D-11 Stand

General Description - This stand is a general purpose stand for testing both shaft-driven and air turbine-driven fuel pumps and controls.

Stand Capabilities

Drive: 250 hp dc motor; variable speed, gearbox output to 5500 rpm maximum

Air Supply: 8.4 lb per second at 110 psi and 400°F.

Fuel System Capacity: Up to 100,000 pounds per hour test pump discharge at 1000 psi and 250°F maximum; closed loop system.

Altitude Exhaust: Fuel supply tank to 60,000 ft on open loop system.

Simulations of the electrical inputs for the electronic EPR and electronic airflow controls will be provided on the test stand.

(20) D-12 Stand

General Description - This is a general purpose fuel test stand for shaft driven pumps and controls.

Stand Capabilities

Drive: 400 hp dc motor, variable speed, dual-pad gearbox, output to 5000 rpm and 16,000 rpm.

Air Supply: 8.4 pounds per second at 110 psi and 400°F.

Fuel System Capacity: 120,000 pounds per hour test pump discharge at 1000 psi and 250°F maximum, closed loop system.

Altitude Exhaust: Fuel supply tank to 60,000 ft on open loop system.

Simulations of the electrical inputs for the electronic EPR and electronic airflow controls will be provided on the test stand.

(21) D-16 Stand

General Description - This is a hydraulic pump test stand.

Stand Capabilities

Drive: 150 hp eddy-current clutch; gearbox output speed, variable to 5500 rpm maximum.

Fuel System Capacity: 120 gpm at 3000 psi and 350°F maximum. Boost pump pressure of 125 psi.

Test Chamber: Inert atmosphere at 400°F to 1200°F.

(22) D-18 Stand

General Description - This is a general purpose fuel pump and control stand.

Stand Capabilities

Drive: 250 hp dc motor

Fuel System Supply: 120,000 pounds per hour at 1000 psi, and 100°F and 12,000 lb per hour at 3000 psi.

Air Supply: 8.4 pounds per second at 110 psi and 400°F.

Simulations of the electrical inputs for the electronic EPR and electronic airflow controls will be provided on the test stand.

(23) D-24 Stand

General Description - The purpose of this stand is to conduct sea level and altitude testing of engine accessory and power takeoff gearboxes, oil systems, and auxiliary mechanical systems.

Stand Capabilities

Drive: One 1500 hp eddy-current clutch drive, variable speed, and gearbox, variable speed. One 400 hp variable speed drive and gearbox.

Test Chambers: Rig mounted, inert gas atmosphere at temperatures of 400°F to 1200°F.

Air Supply: 1.4 pounds per second at temperatures up to 1000°F and pressure to 375 psi.

Altitude Exhaust: 0.3 pounds per second airflow at 2 inches of mercury absolute.

(24) Ignition Laboratory

General Description - The FRDC Ignition Laboratory can perform electrical and environmental tests on ignition systems and components, and is also equipped for maintenance of these items.

(a) G-3 Bench (Available)

Test Chamber: Main - 20 in. x 20 in. x 20 in. (Modified for JTF17A-21 engine by July 1967.)

Igniter - 5 in. x 5 in. diameter

Temperature Range: -200°F to 250°F (Modified for JTF17A-21 engine by October 1967.)

Vacuum Range: Main - 1 micron Hg abs to atmospheric

Igniter - 1 micron Hg abs to 400 psia

(b) G-16 Bench (Available)

Pressure: 1000 psi maximum (Nitrogen)

Vacuum: Bell jar; to zero microns

Power: 28 volt dc, variable voltage

(c) G-17 Bench (Available)

Pressure: 1000 psi maximum (Nitrogen)

Vacuum: Bell jar; to zero microns

Power: 28 volt dc, variable voltage

(d) G-18 Bench (Available)

Power: High voltage, 0 to 30K volt

(25) Electronic Fuel Control Stands

General Description - Two additional electronic fuel control stands are required to support the program. Each will be suitable for calibrating, reprograming, and maintaining the digital electronic engine pressure ratio (EPR) control and the digital electronic airflow computers by simulating inputs, measuring outputs, simulating output loads, and accomplishing troubleshooting.

Stand Capabilities

Air Supply: Clean, dry supply of 100°F, 125 psi air.

Electric Power: Electric power, 3-phase 400 cycle 208/115 volt, single-phase 110 volt 60 cycle, and 28 volt dc will be provided.

Cooling System: A small recirculating system will be provided for cooling test units.

Input Simulators and Load Simulators: To simulate inputs and loads.

Electronic Test Equipment: Digital equipment to perform computer programing, test equipment for general troubleshooting and interconnecting harnesses and plumbing.

(26) Data Recording Carts

General Description - The carts will be used to monitor and record the transient and/or frequency response of the various engine components. Each cart will operate independently and more than one cart may be used on one stand, as required.

Equipment Provided on Each Cart:

1 Recording Oscillograph
3 digital to analog converters
1 Bridge Balance Network
1 Power Supply

G. PROJECT MANAGEMENT

The project engineering system which has been used for the past twenty years by Pratt & Whitney Aircraft and more recently in the highly successful J58 and RL10 programs, places total responsibility for the conduct of the development program in the hands of a single autonomous engineering group. The relationship of the project engineering group to the Program Manager and to the functional departments is described in Volume V, Report I.

Project Engineers and Assistant Project Engineers further delineate, by engineering order supplements, specific requirements of the design, procurement, manufacture or test of the component or portion of the program for which they have been delegated responsibility by the Development Manager. In each case these engineers have complete responsibility to judge whether the efforts of the service groups have satisfied their requirements. As a specific example, the Project Engineer's or Assistant Project Engineer's approval is required on all drawings released by the design group.

As drawings are released, Experimental Engineers reporting to the Project Engineer are assigned to follow the progress of the parts through the process of experimental manufacturing. Quality control and inspection results must satisfy the Experimental Engineer who reports his findings to his Project Engineer. The same Experimental Engineer follows the progress of these rig or engine parts through build in experimental assembly, test, teardown, inspection, and data analysis. The Experimental Engineer thus has a unique opportunity to judge the results of design and manufacture on engine performance and reliability. Rapid feedback of information from all phases of the engine development with maximum continuity of effort is maintained by this close follow-up. Project Engineers and Assistant Project Engineers coordinating the efforts of their assigned Experimental Engineers can react quickly to test results and institute changes in design, material, manufacturing methods, or assembly methods as required.

In a fast moving development program it is essential to incorporate immediately the changes found necessary through test experience. One method of accomplishing this is to institute minor design changes on an informal engineering sketch provided by the Experimental Engineer. Often, modified parts made according to these sketches are available within hours for inclusion in an engine or test rig build. These sketches are filed as a permanent record for design use. They are then incorporated as design changes on the engine assembly drawings if test results warrant.

Weekly project meetings are held by the Development Manager, attended by Project Engineers, Assistant Project Engineers and key Experimental Engineers, and representatives of those service groups associated with the current phase of the project development, to maintain flow of information, to keep overall objectives before the group, and to obtain cross-fertilization of ideas.

SECTION II
COMPONENT DEVELOPMENT TEST PLAN

A. INTRODUCTION

Although full scale engine testing is of major importance in evaluating over-all engine durability and performance, experience has proven that this testing must be preceded and supported by a carefully integrated, well planned, and rigorously implemented component development program. An integrated component and engine development program will assure achievement of the performance and reliability required for commercial operation of the JTF17 engine on schedule and for minimum cost. Component development test rigs are used to accomplish the following:

1. Component design selection testing
2. Component design verification testing
3. Economical sub-system performance and durability testing
4. Component off-design performance and durability evaluation testing which includes: (a) operation outside engine match conditions to determine and develop required margins, and (b) accelerated "weak-link" endurance at operating conditions more severe than engine conditions.

During Phase II-C, JTF17 component testing has been conducted for the purpose of selecting and verifying initial designs. This testing will be intensified early in Phase III as the prototype engine development begins. The component improvement resulting from the accelerated component test program early in Phase III will eliminate many engine problems.

As the engine test program continues, the component program is essential for evaluating the effect of modifications on components and engine performance and durability. Since the component test rigs are relatively inexpensive to operate and more readily available for test, it is possible to test several different configurations in a rig within the same amount of time it would normally take to test one configuration in the full scale engine. In this way, modifications indicated by engine test can be easily and quickly previewed to determine changes worthwhile for engine test. This process of component and engine testing is continued throughout the development program, not only to correct problem areas but also to support growth of the engine. The component test program is coordinated with the engine program by the Project Engineer, who directs data analysis, redesigns, procurement, and testing as necessary to meet over-all program requirements.

In a typical component rig, a portion or a complete section of the full scale engine is duplicated and the component functions essentially as it would during full scale engine operation. Compressor and combustor rigs are examples. Their use permits operation of the component over a broader range than possible when matched to a single operating line as in an engine. The so-called "off-design" performance data thus obtained contributes immeasurably to achieving the proper match of the compressor to the engine, as well as enabling investigation of the component performance at altitude and other operating conditions not easily simulated in normal sea level static testing.

There are numerous other types of rigs which come under the category of validity testing and are used primarily for economic and safety reasons, inasmuch as a failure of certain test parts in a full scale engine could result in a failure of several other parts or components. For example, burst testing of compressor and turbine disks cannot be conducted economically in a full scale engine. Another useful category of component testing is structural stress evaluation of prime engine structures that could be accomplished only by subjecting an engine to violent aircraft maneuvers. Proof tests involving a very high number of stress or thermal fatigue cycles, which would represent thousands of hours of engine testing, can be readily accomplished on rigs in a short period of time.

The Phase III test program that follows describes how each component of the JTF17 engine will be developed using component rigs to supplement the engine program as required to meet FTS requirements and to support the flight test program. A time phase chart of the overall component test plan including relationships and continuity of the Phase III complete engine development is shown in Volume IV, Report E, Section I and also in the detail work plan of Volume V, Report H. The component test program will be continued in phases IV and V to supplement the engine test program as required for engine certification and to meet service life requirements for economical operation of a commercial supersonic transport.

B. MAJOR COMPONENT DEVELOPMENT PROGRAM

1. Fan

a. Introduction

(1) Background

A comprehensive fan component development program will be conducted in conjunction with the JTF17 engine development program. Pratt & Whitney Aircraft's extensive experience during 8 years of high performance fan testing, backed by 18 years of axial flow compressor testing, results in proven methods for designing and developing reliable fans and compressors. This experience was gained not only from the current Phase II-C program, but also from component development necessary for current production fan engines such as the JT3D, JT8D, TF33, and TF30; from company-funded development of the JT9D; and from Government- and company-funded continuing research programs that have advanced the fan state-of-the-art, both aerodynamically and structurally.

The JTF17 two-stage fan divides the engine airflow with a 1.30 duct-to-gas generator bypass ratio and operates with a design pressure ratio of 2.9 for the duct discharge and 2.68 for the gas generator. Component testing will allow accurate determination of critical parameters such as stall margin, off-design efficiency, and stress. These parameters are difficult and expensive to determine in engine testing.

The fan component development program presented in this section is required to support the engine development program by ensuring that performance and durability goals are met on schedule and within specification guarantees. The overall program objectives, types of rigs required, and plans of specific tests show Pratt & Whitney Aircraft methods for developing the fan. These methods assure a program for developing the

fan for the JTF17 engine that will coordinate requirements for complete engine operation as well as requirements for compatibility with the aircraft systems.

(2) State-of-the-Art

Data from a review of single-stage test results, cascade test results, and all associated information that represents the state-of-the-art were used in the design of the prototype fan. This information, in addition to the data from Phase II-C of the SST program, was used to ensure that individual rotor and stator performance levels were sufficient to meet the overall performance requirements. Although the configuration chosen represents an advancement over current commercial engine state-of-the-art, the stage performance is not beyond that of other similar fan stages. High Mach number technology resulting from over 22,000 hours of development testing of the J58 engine is also reflected in the fan design.

Throughout the development program of the prototype engine fan, other Pratt & Whitney Aircraft fan programs will be reviewed for information that may aid development of the JTF17. Two programs that will be particularly beneficial to the prototype are the company-financed JT9D and the Advanced Manned Strategic Aircraft (AMSA) program. A comparison of fan design parameters (table 1) illustrates the advanced state-of-the-art of the AMSA fan and the similarity of the JT9D and the JTF17.

Table 1. Comparison of Fan Design Parameters

	JTF17	AMSA	JT9D
Specific Flow, (lb /sec ft^2)	41.2	43.1	41.0
Number of Stages	2	1	1
Duct Pressure Ratio	2.9	2.2	1.55
Duct Efficiency, (%)	79	80	90
Fan Tip Speed, (ft/sec)	1694	1832	1430

(3) Phase II-C Development

The results of the Phase II-C fan component development program, as well as the successful test stand operation of initial experimental engines, have contributed substantially to the design of the prototype engine.

Initial testing of the fan in the 0.6-scale fan rig, which is aerodynamically identical to the JTF17 650 lb/sec engine, defined the fan performance map and allowed improvements to be incorporated in the first engine. Figures 1 and 2 show the improvements in fan high speed surge line and flow made by modifying the shape of blade part-span shrouds and the fan splitter.

The second experimental engine incorporated additional changes in 1st- and 2nd-stage blades that improved part speed or cruise performance while improving surge margin at sea level takeoff (SLTO). This fan configuration requires a slight increase in operating speed to meet the design airflow at SLTO, but will permit the experimental engine to run to full thrust and permit the evaluation of overall performance and durability.

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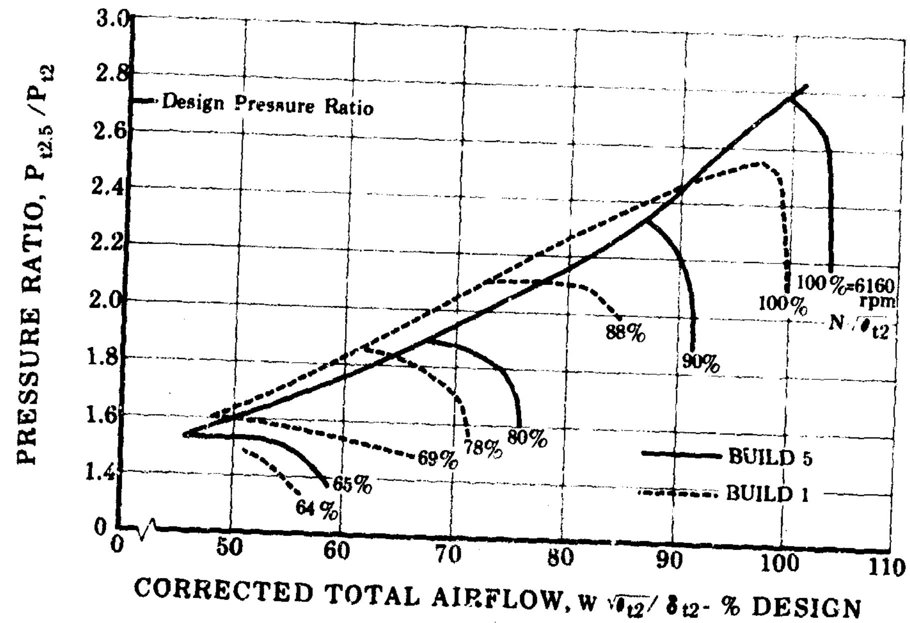

Figure 1. Effect of Modifying Blade Part-Span Shrouds and Fan Splitter on Duct Side Fan Performance

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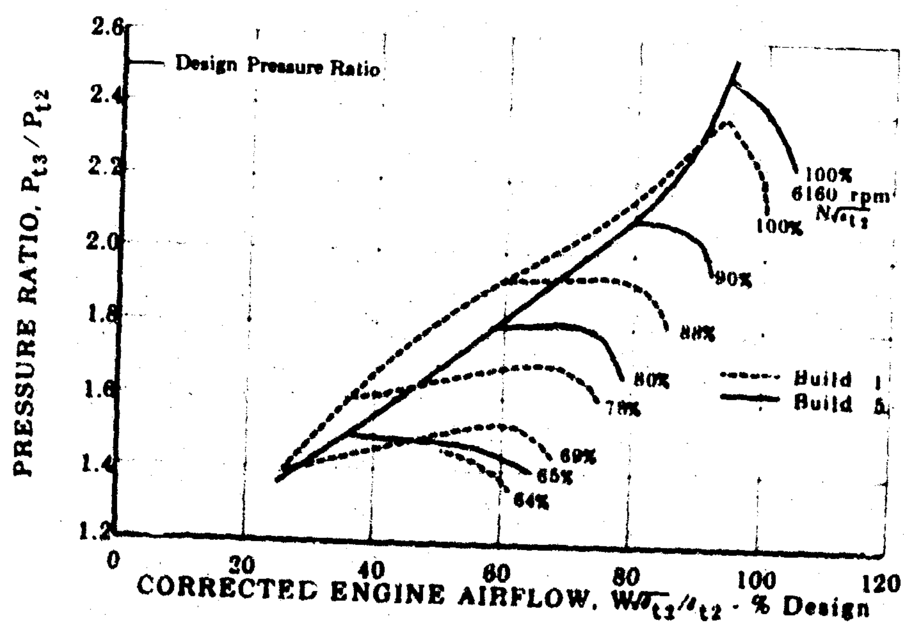

Figure 2. Effect of Modifying Blade Part-Span Shrouds and Fan Splitter on Engine Side Fan Performance

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In addition to supporting the current experimental engine program, the fan component development program of Phase II-C has provided substantiation for the current prototype fan designs.

The fan component development has substantiated the design changes listed below. (See Volume III, Report B for details of these changes).

1. The feasibility of increasing engine airflow from 650 lb/sec to 687 lb/sec by having demonstrated higher specific flow than required.
2. Redesign of the fan splitter to better control bypass ratio.
3. The blading design of both stages to improve the prototype surge margin over that of the Phase II-C engines.

The continuing fan component development program for Phase II-C will evaluate the 0.6-scale version of the prototype 2nd-stage blade during testing scheduled for September 1966.

b. Test Objectives for Phase III

The test objectives of the Phase III fan component development program are listed below. When feasible, testing will be accomplished in a coordinated program of engine development tests as well as component rig tests.

1. Develop adequate surge margin to ensure against engine surge in all transient and steady-state operations.
2. Obtain the required fan speed-flow characteristics and determine the bypass ratio necessary to meet engine requirements.
3. Develop the required fan efficiencies to meet engine performance goals throughout the engine operating envelope.
4. Develop the fan to be compatible with the airframe inlet by running special inlet test programs and flow distortion tests.
5. Provide a satisfactory discharge profile to the high compressor, matching the fan to the high compressor as required.
6. Ensure that the fan is free of aeroelastic stress or mechanical vibration problems under simulated operating conditions up to full cruise Mach number.
7. Demonstrate fan durability by repeated surges and accumulation of test time.
8. Determine the effects of variation in Reynold's number on performance of the fan and make changes necessary to meet cruise performance requirements.
9. Establish the structural integrity of the front mount and other fan cases in static load tests.
10. Analyze test results for substantiation of design criteria for blade containment and disk speed margin whenever off-design operation provides the data.

c. Description of Fan Test Rigs

(1) Fan Test Rigs

The currently available 0.6-scale fan test rig will be used for test programs during the initial portion of Phase III testing. This testing will be accomplished in the Willgoos Turbine Laboratory and other test facilities available at Pratt & Whitney Aircraft in East Hartford, Connecticut. After completion of new test facilities at the Florida Research and Development Center, fan component testing will be accomplished in Florida with full scale fan test rigs.

(a) Scaled Fan Rig

Initially in Phase III, the 0.6-scale fan rig used in Phase II-C will be modified to be aerodynamically like the prototype engine fan. The flow path and the airfoils of the scaled fan rig are exactly 0.61 times the size of the engine fan. A cross section of the Phase II-C scaled fan rig is shown in figure 3 and an external view of the rig in figure 4. The structural design of the rig, including the disks and rotor spacers, is unique to the scaled rig. The rig inlet system consists of a sheet metal bellmouth and an instrumentation ring with struts for supporting a stationary centerbody and slip rings for obtaining rotating stress data. The fan rig consists of the 1st- and 2nd-stage rotor assembly and the 1st-stage stator. The 2nd-stage vanes, the duct exit guide vanes, and the flow splitter are housed in the exhaust system cases. The exhaust system consists of coannular duct work for the duct and gas generator air streams, which exhaust separately into facility collector rings.

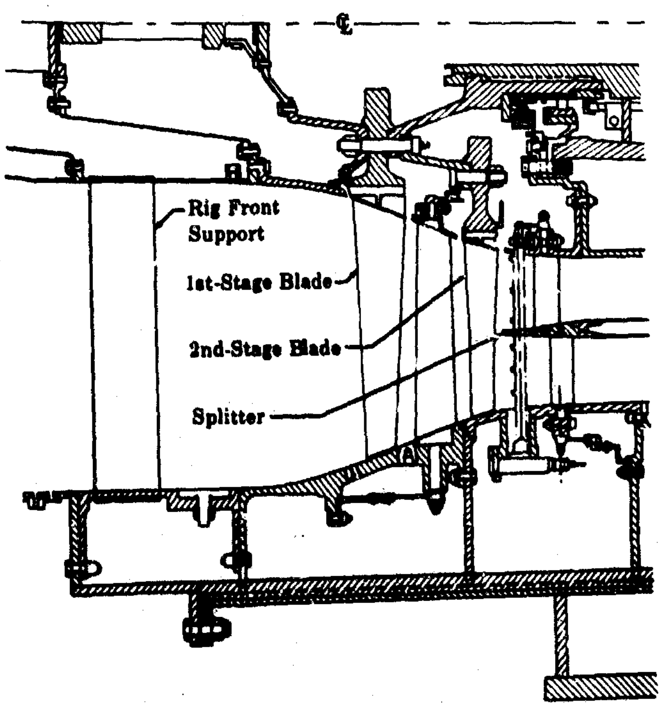

Figure 3. 0.6-Scale Fan Test Rig

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Figure 4. Scaled Fan Rig Mounted on Test Stand X-20331 EII

The rig is designed to flow 256 lb/sec total airflow at a pressure ratio of 2.9 for the duct discharge and 2.68 for the gas generator with a bypass ratio of 1.30 at a corrected rotor speed of 10,630 rpm. Variable stagger vanes are incorporated in the 1st-stage stator and the duct exit stator so that these vanes may be restaggered to induce a wider operating range of the fan stages for determining performance improvements. The vanes in the 2nd-stage stator are fixed because adjustment would not be possible with the rig at test. The leading edge of the airflow splitter, which separates the fan airflow into the duct stream and the gas generator stream, is replaceable so that different configurations can be installed for evaluation. Phase II-C testing has shown that the surge characteristics and the bypass ratio of the fan are significantly affected by the shape of this splitter.

The rotor assembly, which is cantilevered from the front bearing, is driven from the rear of the rig. This allows removal of the 1st-stage disk or the fan rotor and case assembly from the rig at test without disturbing the rig alignment or the ring for discharge instrumentation. This facilitates rapid changes of rotors so that more than one configuration can be tested in a single test stand mount.

In early 1967, a second 0.6 scale fan rig will be built to provide the capability for inlet compatibility and noise suppression development tests. This rig will have an additional feature incorporated to allow simulation of the high compressor back pressure effects while running inlet distortion tests. (See Volume III, Report D.) This will be accomplished by incorporating a flow controlling device in the gas generator discharge area of the rig exhaust duct. By controlling Mach number of the discharge air in the various circumferential sectors of the

discharge duct, the stabilizing effects of the high compressor can be simulated on distorted inlet fan performance.

(b) Full-Scale Fan Rig

The 0.6-scale fan component testing has proved valid in excellent correlation of test results between the rig and engine during Phase II-C. However, the added benefit of full-scale testing makes it desirable to test the full-scale fan as development progresses through the prototype phase. The advantages offered by full-scale testing are:

1. Elimination of special scale parts
2. Common rig and engine parts allow direct early engine testing of improved fan configurations, thus adding program versatility.
3. Testing will demonstrate fan durability by repeated surges and accumulation of test time.
4. Aeroelastic and mechanical vibration testing will be directly applicable to the engine development.
5. Using engine parts, the full-scale rig will be capable of operation at engine cruise conditions.
6. Fan design details which cannot always be scaled because of mechanical considerations, such as tip clearances and blade shroud thicknesses, will therefore, not introduce rig-to-engine performance differences.

The basic full-scale rig will consist of the engine rotor and case assembly (rotor assembly with 1st-stage stator assembly), an inlet case with front mount, an intermediate case, and test stand adapting cases. The rig inlet will use the engine test bellmouth and instrumentation ring with struts to support a stationary centerbody that will contain the slip ring assembly used to obtain rotating stress and temperature data.

The rig front mount case can use less critical materials than the engine and will incorporate special rig instrumentation and mount provisions. Variable stagger vanes will be incorporated in the rig as alternative parts. They will be used when the versatility of variable stagger parts will not conflict with program requirements for exact duplication of the engine parts. The intermediate case will duplicate the engine flow path and strut system, and will include special features required for instrumentation and thrust balance. This case will house the bearing compartment. The fan rotor will be cantilevered as in the engine. A special coupling shaft to take the place of the engine low turbine shaft will drive the rig. Coannular exhaust cases will carry the duct and engine section flow to the test facility discharge ducts which will include provisions for setting the required back pressure.

The materials used in the full-scale rig will allow operation at full Mach number heated inlet conditions to allow exact cruise performance testing as well as vibration analysis under heated inlet conditions.

(2) Special Instrumentation

Full evaluation of the performance characteristics of any compressor requires adequate instrumentation to accurately and completely define stage performance, overall fan performance, and the problem areas.

Three general types of instrumentation will be used in the evaluation of JTF17 fans. These types include fixed instrumentation, rotating instrumentation, and probing equipment.

(a) Fixed Instrumentation

Fixed instrumentation, by far the most frequently used type in fan development, includes removable probes and rakes to measure pressures and temperatures at the inlet and discharge of the rig, and instrumentation permanently fixed to the vanes and cases. The probes and rakes at the inlet and discharge of the rig are used to determine overall performance of the fan. The permanently attached instrumentation includes pressures and temperatures on the leading edge of vanes (figure 5) and wall static pressure taps at the leading and trailing edge of the vanes. This instrumentation is essential in fan development to define the radial and circumferential flow distribution characteristics and stage performance. Readings from this instrumentation are important in the data input for the computer analysis decks which calculate the flow streamlines that are used in detail analysis of fan performance.

Figure 5. Leading Edge Instrumentation on 1st-Stage Adjustable Vanes — XP-63824 EII

Strain gage instrumentation, as well as the skin thermocouples, will be used on stationary parts as required in the structural evaluation of the fan.

(b) Rotating Instrumentation

Rotating instrumentation will be used for stress and temperature measurement on rotating parts of the fan. Strain gages for measuring dynamic stresses on blades and disks are normally installed on all new configurations to verify the design calculations for vibration and aeroelastic stresses. Rotating thermocouples will be installed to determine thermal gradients in the parts at various operating conditions, to supplement the data obtained from engines during heated inlet

testing. The ability to operate the fan rig at off-design conditions provides a more complete map of the rotating stresses than is obtained from engine testing that is limited to a specific operating range.

(c) Probing Equipment

Probing equipment is used to obtain pressure and temperature profiles and air angles within the fan to supplement calculated values. Probing equipment consists of a remotely operated linear traverse actuator with an appropriately designed probe that can be radially traversed across the air stream at any desired location. The probes are available to determine boundary layer thickness and to measure static pressure, total pressure, total temperature, and air flow angle. Provisions are included in the rig design for traversing behind the rotors and in the rig discharge. Occasionally, a program will require traversing in front of a rotor. These provisions will be added, as required, during the build of the rig.

(3) Test Facilities

Facilities for testing the fan rig include three existing compressor test stands at Pratt & Whitney Aircraft in East Hartford, Connecticut. A new, high capacity test stand capable of testing full-scale JTF17 fan rigs will be built at the Florida Research and Development Center. The capabilities of these stands are described below.

(a) Pratt & Whitney Aircraft, East Hartford, Connecticut

Test Stand X-204, located in the Willgoos Laboratory, is used for testing multistage and fan compressors. The test rig is driven through a gearbox by a 24,000 hp reversible electric motor. Power for the motor is obtained from four 6000 hp steam turbines driving variable-speed AC generators. Three speed ranges are available from the gearbox with speeds up to 15,000 rpm. This stand is connected to ram compressors and refrigerated air at the inlet and exhausters on the discharge as well as to an atmospheric inlet and discharge. Inlet airflow is measured by an appropriately sized orifice in a 54-inch diameter duct. The gas generator stream airflow is measured by an orifice in a 36-inch diameter duct.

The stand has data recording provisions for reading 466 pressure channels and 280 temperature channels in the control room.

Table 2 summarizes the conditions that can be maintained at the inlet of the rig.

Table 2. Rig Inlet Conditions

Atmospheric Air Inlet	210 lb/sec actual airflow at 22.5 in. HgA with 42-inch diameter orifice.
Compressed Air (Approx Max)	400 lb/sec actual airflow at 40 in. HgA and 150°F due to heat of compression.

Table 2. Rig Inlet Conditions (Continued)

Refrigerated Air	130 lb/sec actual airflow at -15°F up to 30 in. HgA 100 lb/sec actual airflow at -35°F up to 40 in. HgA 60 lb/sec actual airflow at -50°F up to 40 in. HgA
Heated Air	
Atmospheric Air Heater	83 lb/sec actual airflow at 275°F 153 lb/sec actual airflow at 220°F
High Pressure Air	56 lb/sec actual airflow at 170°F to 40 in. HgA

Test Stand X-211, located in the Willgoos Laboratory, is used for testing multistage and fan compressors with ambient conditions at inlet. The test rig is externally driven through a gearbox by a 40,000 hp steam turbine. Two speed ranges are available with speeds to 11,000 rpm. The air supply at the inlet to the rig is at ambient atmospheric temperature and pressure, with a throttled inlet minimum pressure of 3 in. HgA. Inlet airflow is measured by an appropriately sized orifice in a 72-in. diameter duct. The gas generator stream airflow is measured by an orifice in a 60-in diameter duct. The stand has data recording provisions for reading 260 pressure channels and 308 temperature channels in the control room.

Test stand X-17, located in the main test area, is used for fan and multistage compressor rig testing. The test compressor is driven through a gearbox by a Pratt & Whitney Aircraft FT4A-6 free turbine engine that delivers a continuous rating of 24,200 hp and a maximum intermittent rating of 28,300 hp at 11,000 rpm rig speed. Air at atmospheric pressure and temperature is supplied to the compressor inlet and exhausted to atmospheric conditions. The inlet duct diameter is 72 inches, and inlet airflow is measured by a calibrated bellmouth. The gas generator stream airflow is measured by an orifice installed in the 36-in diameter exhaust duct. The stand has data recording provisions for reading 423 pressure channels and 250 temperature channels in the control room.

A central automatic data recording (ADR) system serves both X-204 and X-211 compressor test stands. Airflow, pressures, temperatures, rotational speeds and electrical signals are automatically recorded at steady-state conditions to determine performance characteristics. ADR consoles in each control room permit control of the system and insertion

of fixed data to identify all test conditions. The system has a capacity to record 489 variables in addition to the fixed data from each test stand. Data acquisition time is less than one minute.

(b) Florida Research and Development Center

A new facility for testing full-scale JTF17 fans and high pressure compressors will be available in March 1968. This stand will be located in the High Mach Number Turbine Laboratory and will be designated as C-7 stand. The test compressor will be driven through a gearbox by two Pratt & Whitney Aircraft GG4's and a Worthington Double Flow Power Turbine delivering 52,500 hp.

The stand will have atmospheric inlet and discharge and also have ram and heated inlet capability and discharge capability to exhausters. Inlet airflow will be measured by an orifice in the inlet duct. The gas generator stream airflow on fan rigs will be measured by an orifice in the discharge duct.

Table 3 summarizes the conditions that can be maintained at the inlet and discharge of the rig. Additional details of this stand may be found in Volume V, Report B.

Table 3. Rig Inlet and Discharge Conditions

Compressed Air	400 lb/sec actual airflow at 120 in. HgA
	480 lb/sec actual airflow at 70 in. HgA
	510 lb/sec actual airflow at 50 in. HgA
Heated Air	500°F at 303 lb/sec actual airflow and 26 in. HgA
	700°F at 250 lb/sec actual airflow and 120 in. HgA
Exhauster Capacity	250 lb/sec actual airflow at 15 in. HgA discharge pressure
	20 lb/sec actual airflow at 1.5 in. HgA discharge pressure

This test stand utilizes a centrally located Automatic Data Recording and Processing System which will record data from 369 channels for both steady-state and transient conditions. The transient recording system is extremely useful for recording the exact conditions in the test compressor to define the surge line. The processing system will provide computed performance information in the control room while testing is in progress. Sufficient instrumentation will be installed in the control room to monitor all the critical data channels during test.

d. Fan Test Programs

Fan rig testing will provide the JTF17 engine program with fan configurations to meet the engine goals for specific fuel consumption, thrust, and durability. The most promising rig configurations tested will be further evaluated in the engine test program. The results of engine testing will then be fed back into the rig program. The component test program provides the means for making fan compressor evaluations more quickly and economically than would be possible in an engine. Heated inlet air tests will be

run as well as ambient inlet air tests after the Florida Research and Development Center test stands for fan rigs and full-scale fan rigs are available. These tests with heated inlet air will simulate aerodynamic and mechanical effects of fan operation exactly as they occur in engine operation throughout the flight envelope. The following paragraphs describe the types of tests and a typical fan development test cycle anticipated to develop the JTF17 fan to fully meet its requirements.

(1) Category of Tests

Five major types of tests will be conducted during the fan development program: (1) clean performance tests, (2) overall and stage performance tests, (3) stress documentation tests, (4) inlet compatibility tests, and (5) fan noise suppression tests. In the fan development program it will be necessary to utilize the available time and facilities in the most efficient and economical manner. For this reason, a test program is seldom conducted with only one objective in mind. The test types are described below.

(a) Clean Performance Testing (Design Verification Test)

This testing will completely document the overall performance of the fan without the influence, even though it is expected to be minor, of interstage or stress instrumentation. Only normal engine inlet and discharge instrumentation will be used in these tests to develop both duct and engine compressor maps. This type of test will be run on the finalized fan configuration selected for Flight Test Status (FTS) engine and again on the finalized fan configuration selected for engine-type-Certification engine. The parts used will be new parts rather than reoperated parts used in other phases of the development program.

(b) Overall and Stage Performance Tests

This testing will fully document the aerodynamic performance of the compressor. Overall and stage performance testing that provides the data necessary to improve fan performance will represent the majority of the testing during the fan development. Interstage instrumentation, consisting of vane leading edge thermocouples, total pressure taps, and wall static pressure taps at vane leading and trailing edge planes, will be installed for these tests, as well as inlet and discharge instrumentation. During the test program that will completely define the fan performance from choke flow to surge, particular attention will be paid to the interstage data, because it will provide the information required to evaluate the performance of and determine modifications to the fan stages. Parts used in this testing will often be fabricated by recoining or recambering existing parts to alter the aerodynamic characteristics of blades or vanes, as indicated from data analysis, for performance improvements.

(c) Stress Documentation Tests

Blade vibration is a major area of concern in an engine fan or compressor design. Stress documentation tests will be run to survey and record the dynamic stresses during operation of the fan rig throughout simulated flight operating conditions and at off-design conditions. Data from these tests will be used for certification requirements to demonstrate acceptable levels of blade and disk vibratory stress. The vibration takes the form of resonance when excitation is present to excite the blades in their various natural frequency modes. These excitations may be the result of inlet pressure distortion, periodic or semi-periodic flow distortions, or structural features in the flow pattern, either upstream or downstream. The blade vibration may be present either in the form of the original excitation or a harmonic that follows a Fourier expansion. The vibration may take the form of self-excited instability (flutter), which is an interaction between the elastic systems and smoothly flowing air. To evaluate these forms of vibration, strain gages are used extensively on the blading during fan rig tests to verify the lack of any excessive stresses. The strain gage data are monitored during fan test to assure rig safety and are recorded for detailed evaluation.

Buffeting stress levels noted during evaluation of the strain gage data are useful in assessing heavy aerodynamic stage loading due to aerodynamic mismatch between stages. Buffeting stresses are characterized by bending vibration that pulsates in an irregular manner. This pattern may also be detected just before surge. The ease of operating the rig at off-design conditions, including surge, will provide a more complete map of the dynamic stresses than is possible during an engine test. Provision for heated inlet air will permit measuring the stresses at simulated flight operating temperatures and pressures. Information from these tests will be incorporated in modifications to the engine design where necessary to assure that the aeroelastic design is adequate for all engine operating conditions.

Extensive temperature instrumentation, including rotating thermocouples, will be installed on some builds in support of the engine program to measure the fan internal temperature levels and gradients at inlet conditions that simulate the extremes of the flight envelope. This information will be used to verify the design temperature estimates where parts life is critical to temperature.

(d) Fan-Inlet Compatibility Tests

These tests will be accomplished on fan component test rigs as well as a special inlet compatibility test engine (see Volume III, Report E, Section III). Experience in other engine programs has indicated that this testing must be initiated early in the development program to provide adequate tolerance to the inlet profiles that will be present at the engine inlet in flight. Close coordination will be maintained with the aircraft contractor to ensure that the latest information available is used to determine the inlet profiles for these tests.

Early in Phase III the 0.6-scale fan rig will be used to run inlet distortion tests with screen distortion generators to create the inlet

pressure profiles. A simulated aircraft inlet duct will be used in later tests when its configuration is finalized by the aircraft contractor. The fan component rigs will be tested with flow controlling vanes in the gas generator discharge duct of the rig which will simulate the effects of the high compressor. Stress documentation data will normally be taken during these tests so that any abnormal stresses induced by the inlet distortion may be measured. This stress data and fan performance analysis will be used for design corrections to ensure the fan's capability to meet its requirements for engine durability and performance while operating with inlet distortion.

A special inlet compatibility test engine will be run to determine the interaction effects of the high compressor to stabilize fan performance while operating with inlet distortion. This engine will be a modified Phase II-C engine that can operate on a sea level test stand with simulated cruise conditions in the fan and high compressor. Test results from this engine program will verify the validity of the single spool fan rig data and will allow better simulation of the high compressor effects in those rigs.

Continued periodic engine tests with inlet distortion and heated inlet simulated cruise conditions will verify the validity of inlet distortion test results from both types of fan rigs. The best performing fan configurations from rig tests will be incorporated in these engine tests. Additional details of the inlet compatibility test program may be found in Volume III, Report E, Section III.

(e) Fan Noise Suppression Tests

Fan component rigs will be monitored and measurements recorded to determine fan noise levels. This data will aid in evaluating noise surveys of engine operation and will provide a baseline for fan development testing aimed specifically at noise reduction.

Airfoil loading, rotor-stator spacing, and blade-vane ratio of airfoils are items known to affect the noise generated in the fan. These factors were considered in the original design of the fan and also will be in future changes directed toward performance and durability improvements. A development program is planned to reduce the fan-generated noise levels by varying these factors and initiating design changes for improved configurations. This testing is expected to begin by November 1967.

Additional details of these noise suppression tests may be found in Volume III, Report C.

(2) Fan Development Test Sequence

The JTF17 fan development test sequence will be similar to previous Pratt & Whitney Aircraft Compressor test programs and will include the build of the rig, actual testing of the rig, analysis of the test data, and disassembly and rework of the parts for subsequent builds. Figure 6 shows a chronological chart of a build cycle with average times required for each step.

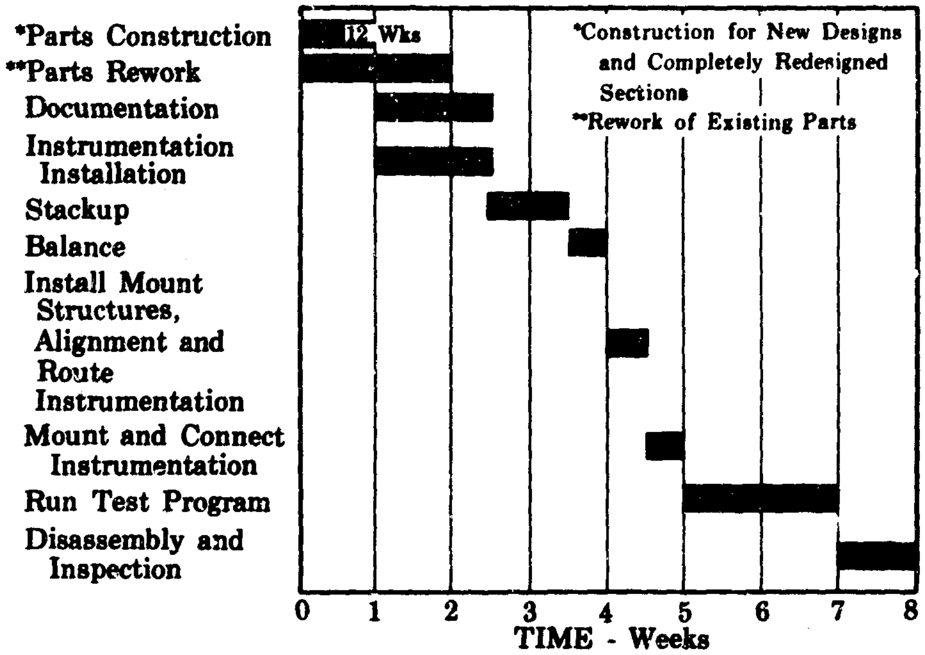

Figure 6. Typical Fan Rig Build Sequence Chart FD 16660 EII

(a) Rig Build

The build of the rig includes the procurement of parts, either new or reworked, inspection and measurement of parts for documentation of the build, installation of fixed performance instrumentation and stress instrumentation as the program dictates, and assembly of the parts into a complete rig.

Procurement of parts may include a complete set for the initial build of a rig, a new set of blades, or reworked parts from a previous build. Long lead-time parts are ordered as far in advance of the desired test time as possible, and parts critical to the development will be expedited to meet test schedules. The long lead-time for new airfoils (6 to 10 weeks) makes rework of existing parts attractive. Wherever results will not be compromised, recoined blades or recambered stators will be tested.

Inspection and measurement of the parts to document the build will include mechanical measurements similar to those taken during an engine build to determine the fit between mating parts and conformance of oil flows and leakage rates to specified values. This type of measurement and check will ensure fewer mechanical problems on the rigs, so that a maximum of information can be obtained from each build. Documentation of aerodynamic parts will include shadowgraphing of blade and vane airfoils, measurement of blade and vane metal angles, measurement of blade tip clearances, and all leakage path clearances, such as interstage knife-edge seals.

During the time that documentation of the build is being made, any rework required for installation of performance and/or stress instrumentation will be made. Builds will often include requirements for both stage performance and stress documentation, which will provide a larger amount of information from one rig build with a minimum of cost. Stress instrumentation that normally consists of strain gages for measuring dynamic stresses will be installed concurrently with documentation of the build.

After the blade and vane instrumentation is completed, the rig is assembled and the fan package is dynamically balanced. The fan package is installed into the rig cases and all instrumentation is led out and identified. The final step in assembly is installation of the rig into the transport stand for delivery to the test stand.

(b) Rig Test

Before delivering the rig to test, written instructions for installing the rig in the test stand and connecting instrumentation will be issued by the Experimental Engineer in charge of the rig test. If the rig includes instrumentation for stress documentation, the portable equipment for recording the stress data will be moved to the test stand for connection during the rig mount.

One or more Experimental Engineers will be in the test stand control room during all testing to direct the test and monitor the data being generated. The availability of computed performance information in the test stand control room during the tests at C-7 stand in the High Mach Turbine Laboratory will greatly aid the Experimental Engineer in his evaluation of the data obtained. Use of this advanced data recording and processing system will assure more usable test data per test hour than has been possible in the past. The rapid availability of calculated performance information to the Analytical Engineers will speed data analysis and thereby reduce the time between end of a test and availability of information for planning additional tests.

The fan is normally tested by setting one side of the fan, engine or duct on a simulated engine operating line and varying the pressure ratio from choke to surge on the other side, while maintaining a constant corrected rotor speed. The processes are repeated for several speed lines between design speed and start conditions to generate a complete performance map for each side of the fan.

(c) Disassembly and Rework

After completion of a test program, the rig is disassembled and a complete inspection made for cracks, foreign object damage, or other signs of distress. Most builds of a fan rig are concerned with determining the surge lines for the duct and gas generator streams as part of the program. The surge line investigations require numerous surges of the rig that often impose high stresses on the blades, and the possibility of fatigue cracks in the blades is always present. If fatigue

cracks occur as a result of numerous surges, a limit will be set for the number of surges that a particular blade may undergo before the blade is retired from the program. All parts are visually inspected and then subjected to fluorescent penetrant inspection magnaflux, or X-ray to check for cracking. All parts found acceptable are then prepared for rebuild.

Recommended reworks of existing parts made as the result of data analysis from previous tests are then incorporated into the parts. Reworks to existing parts may include recambering vanes, recambering or recoining blades, and restaggering blades that would require a disk with a changed broach angle. New parts for major changes will be ordered through normal procurement channels.

(3) Data Analysis

The analytical review of fan test data will be accomplished by the latest methods of fan performance analysis. The analytical methods of fan development differ only slightly from those used for conventional compressors. The differences are mainly those caused by the definition of the flow splitting effects behind the second rotor. The diferences in airfoil section and Mach number of modern low hub/tip ratio compressors and fans require detailed measurement at various radial stations to adequately define the stage characteristics. The JTF17 fan stages are designed to produce a higher pressure ratio across the duct than the gas generator stream. For these reasons, average stage characteristics are used only for comparing matching between stages. Root and tip section stage characteristics are generated for actual detailed analysis of the stage. Another degree of freedom present in fan development is the interaction between the duct and gas generator streams caused by the flow splitting effects behind the last rotor of the fan. From experience on other Pratt & Whitney Aircraft fan engines such as the JT3D, JT8D, TF30, TF33, and forerunners of the JT9D, it is advantageous that the root be operated at lower pressure ratios whereas the outer portion of the span can deliver a much higher pressure ratio. The axial and radial spacing of the flow splitter relative to the last rotating blade row influences this optimization as well as influencing the surge line by locating the flow splitting streamline between the duct and gas generator streams.

As previously indicated, the high speed data recording and processing systems used will provide overall performance data including airflow, corrected speed, pressure ratio, temperature ratio, and efficiency during testing. In addition, computer programs that solve all of the equations of motion and continuity will be used for further processing of the data to compute values of incidence, deviation, stage loading, relative Mach number, and other parameters for all stations throughout the fan. Rapid data analysis is necessary when testing a variable geometry rig to minimize rig idle time after completing the test of a particular stator setting.

The following detail analysis techniques are those normally used for fan data analysis:

1. Overall Performance - Data from the rig tests are used to generate maps of pressure ratio, airflow, and efficiency for the duct stream and gas generator streams of the fan. These maps are compared to design goals and to previous rig tests to determine the improvements in overall fan performance. These comparisons are also necessary to properly match the fan performance to other components for engine operation.
2. Raw Data Profiles - Raw data from the vane leading edge instrumentation and the discharge instrumentation will be plotted against radial and circumferential positions. These plots point out in detail where defects appear.
3. Phi-Psi Analysis - Phi-Psi is a name given the method of nondimensional stage characteristic analysis used by Pratt & Whitney Aircraft in both fan and conventional compressor data analysis. The shape of a nondimensional characteristic curve computed along a streamline will normally indicate the incidence at which the blade section is operating. These parameters are defined as follows:

$$\phi = \frac{\omega\sqrt{\theta}}{\delta} \cdot \frac{(N/\sqrt{\theta})\ \text{design}}{(N/\sqrt{\theta})}$$

$$\psi = \frac{P}{P-1} \cdot \frac{(N/\sqrt{\theta})^2\ \text{design}}{(N/\sqrt{\theta})^2}$$

where:

ω = airflow

$$\delta = \frac{P_{stage}}{P_{standard\ day}}$$

$$\theta = \frac{T_{stage}}{T_{standard\ day}}$$

N = rotor speed

P = pressure

4. Streamline Analysis - Data from the test will be entered into a computer program that will compute the three-dimensional velocity triangles throughout the fan. The air angles into the blading and the turning achieved are then easily obtained.

5. Cascade Analysis - This analysis will show how the blading losses and turning correlate as a function of inlet air angle. Cascade data are not always available on the particular airfoils in use in the fan, but the large amount of data available from the many Pratt & Whitney Aircraft compressor research programs of similar airfoils makes comparison possible.

e. Fan Test Schedule

The schedule for JTF17 fan component development calls for an estimated 50 tests starting in February 1967 and continuing until the end of Phase III in August 1970. The 0.6-scale fan test rig will be used in initial development programs. The twin-spool inlet compatibility test rig will be used to verify the validity of inlet distortion test results from the 0.6-scale rig. After full-scale fan rigs and test facilities become available at the Florida Research and Development Center, the 0.6-scale fan rigs will be phased out of the development program by mid-1968.

The test programs planned during Phase III with predicted test hours are listed below:

1. Eleven combined overall and stage performance, inlet compatibility, and stress documentation tests on the 0.6-scale fan rig will require an estimated 500 hours. Two of these tests will be run with a simulated aircraft inlet duct at the rig inlet to create the desired distortion patterns.
2. Two 0.6-scale fan rig tests will be operated with noise reduction configurations requiring an estimated 120 hours. Overall and stage performance, stress documentation and inlet compatibility evaluations will be included in these test programs.
3. Three full-scale fan rig clean performance tests will require an estimated 90 hours of testing.
4. Four full-scale rig overall and stage performance tests will require an estimated 160 hours of testing.
5. Four full-scale rig combined overall and stage performance and stress documentation tests will require an estimated 180 hours of testing.
6. Three full-scale rig combined inlet compatibility and stress documentation tests will require an estimated 120 hours of testing.
7. Twenty-three full-scale rig combined overall and stage performance, inlet compatibility, and stress documentation tests will require an estimated 1080 hours of testing. Five of these tests will incorporate fan configurations designed for noise reduction evaluation.

The schedule of testing is shown in figure 7, which projects the development beyond Phase III to engine type Certification. The procurement time represents the time required to manufacture new hardware and also the modifications to existing hardware that will occur between rig builds. The cumulative sets of parts required for the program are indicated as they are needed.

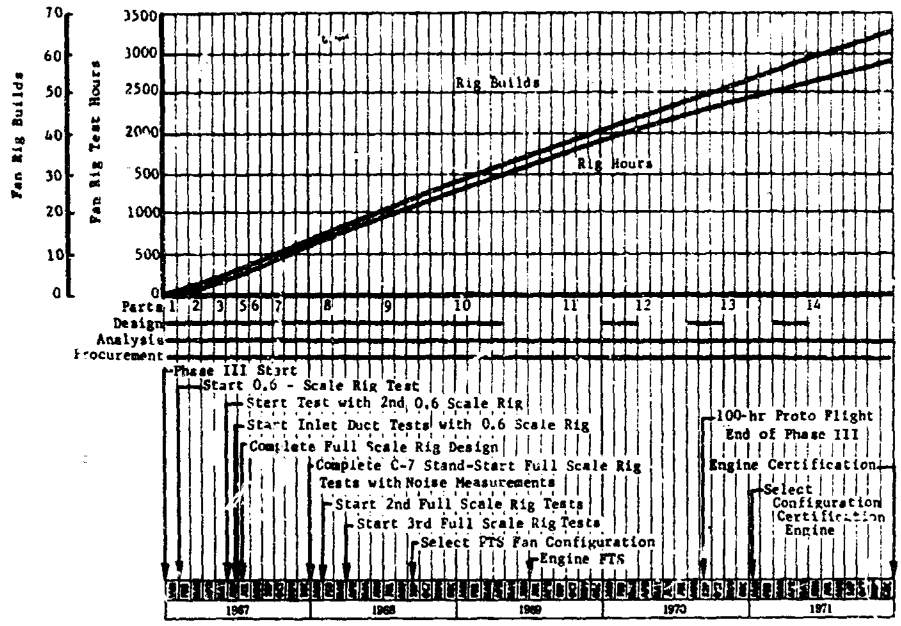

Figure 7. Fan Rig Test Program FD 16489 EII

f. Support for FTS and Engine Certification

Prior to the JTF17 engine FTS test, a fan configuration must be selected to meet the engine performance and durability goals. This configuration will be thoroughly evaluated in fan rig tests prior to building the FTS engine.

Certain design substantiation tests will be accomplished during Phase III that will contribute to the substantiation of the fan design to meet engine certification requirements. The tests that are completed prior to the engine Certification test will, early in the development program, assure the adequacy of design criteria in the areas discussed below. These test results will be analyzed to determine any design corrections that may be necessary.

(1) 1st-Stage Blade Containment

A spin-pit test will be accomplished in which a 1st-stage fan blade will be intentionally failed inside a flight weight case at simulated environmental conditions. The engine and fan component development programs will also be monitored for any instances of this or other blade failures that may occur. Results of these occurrences will determine any design corrections that may be necessary.

(2) Structural Integrity

Tests will be accomplished in a static load test rig to substantiate the structural integrity of the front mount case and the intermediate case. These cases will be stressed with hydraulic load cells to simulate engine thrust and deflection loads predicted for high-g aircraft flight maneuver conditions.

(3) Disk Low Cycle Fatigue Tests

Titanium fan disks will be tested to substantiate the design criteria for low cycle fatigue. These tests will be run in the "Ferris Wheel" rig shown in the turbine section, figure 61. This is a test device that allows simulation of operational disk stresses and can rapidly accumulate low cycle fatigue cycles on an engine disk with hydraulic load cylinders.

2. High Compressor

a. Introduction

(1) Background

A comprehensive high compressor component development program will be conducted in conjunction with the JTF17 engine development program. The development methods used by Pratt & Whitney Aircraft are the result of experience gained in thousands of hours of testing on compressors for the JT3, J57, J74, J75, TF33, JT3D, JT8D, and the Mach 3+ J58 engines. The Project Engineering form of program management for the JTF17 assures a continuous coordination of all phases of the development program, both engine and component, from design through testing and analysis of results.

The six-stage JTF17 high compressor is designed for a 4.8 pressure ratio and 130 pounds per second of airflow. Component development of this compressor is necessary to ensure that the engine performance and durability goals are met on schedule and within the specification guarantees. Component testing in suitable test rigs allows accurate determination of critical parameters such as stress, stall margin, and off-design efficiency, which are difficult and expensive to determine in engine testing. Variable position stators, with their ability to induce a wider range of aerodynamic conditions in the compressor, will be used in some component rigs to accelerate the high compressor development, particularly in the early stages of the test program.

The high compressor development program presented in this section shows the overall program objectives, types of rigs required, specific test plans, and data analysis techniques. This component testing will be coordinated with the overall program requirements to assure an adequate high compressor for successful engine operation as well as compatibility with all aircraft system requirements. Heated inlet testing, used to advantage in the development of the Mach 3+ J58 compressor, will be included in this development program to provide the correct match between aerodynamics and rotor mechanical speeds at simulated high Mach number cruise conditions.

(2) State-of-the-Art

The JTF17 engine high compressor is designed within the present state-of-the-art, although it is more advanced than current commercial jet engines. The average loading per stage ($\Delta P_s/Q$) of the JTF17 rotor is nearly identical to the average of the last six stages of the J58 compressor (0.459 vs 0.455 for the J58). The JTF17 high compressor

average stator loading ($\Delta P_s/Q$) of 0.401 is slightly lower than comparable J58 stages. High Mach number experience gained in the J58 engine development program and related service in the YF12A and SR71 aircraft has provided the technology required for the successful development of a high compressor.

The significant design parameters for the JTF17 compressor are shown in table 4 together with the values for other Pratt & Whitney Aircraft advanced high-pressure compressors.

Table 4. Significant Design Parameters, JTF17 Compressor vs Current Engines

	JTF17	J58	AMSA	JT9D	JT8D
Pressure Ratio	4.83	8.75	6.16	10.0	4
Number of Stages	6	9	7	11	7
Average Pressure Ratio per Stage	1.30	1.27	1.30	1.23	1.22
Specific Flow	36.5	42.7	37.6	37.3	39.9
1st Rotor Tip Speed	1160	1260	1103	1050	1060
1st Rotor Hub-Tip Ratio	0.739	0.485	0.71	0.72	0.775
Adiabatic Efficiency, %	86	80.5	84	85.6	85

During the development of the JTF17, all other concurrent Pratt & Whitney Aircraft compressor development programs will be constantly reviewed for application to the JTF17. The similarity of the J58 and AMSA compressors will make their development significant to the JTF17 compressor program.

(3) Phase II-C Development

The first 6-stage JTF17 high compressor rig build was completed and testing was started 6-1/2 months after the start of the Phase II-C program. The compressor was not completely calibrated because of a 3rd-stage blade failure early in the test program. Improper scheduling of the variable stators and excessive intermediate case strut wakes induced high stresses that failed the blades.

Limited data from the first build and annular cascade testing prompted a change to add strut extensions to the thick intermediate case struts, reducing strut wakes and losses. Reduced leakage at blade roots and variable stator end gaps were also incorporated in the second compressor build.

The high compressor was completely calibrated in Build 2 early in March 1966. This build determined the variable stator schedule used by the first experimental engine, allowing it to run with simultaneous actuation of the inlet guide vanes, 3rd-stage stators and 7th-stage stators on a schedule proportional to the high compressor rotor speed. The calibration was then repeated with two conditions of inlet pressure profiles to simulate the fan discharge at various operating conditions. The overall performance of this testing, identified as Build 3, showed no change from Build 2.

To favor the high speed surge line of the compressor, the first experimental engine was matched to a low operating line. The engine was able to start without using the compressor bleeds because of the good slow speed surge line and high efficiencies of the compressor. The engine completed its first engine build with no compressor problems.

Stator recambering, i.e. reoperations to change stator camber angles, was incorporated in Build 4 as a result of Builds 2 and 3 data analysis to improve surge margin. Before a complete calibration was run, the rig was removed from the test stand because of damaged 3rd- and 4th-stage blades noted during a routine inspection of the rig. The primary cause for the blade damage was foreign object ingestion. However, a slight indication of a rub between the 3rd-stage blades and the inlet guide vanes was noted. As a result, subsequent builds of rigs and engines incorporated cutback trailing edges on the inlet guide vanes to reduce the possibility of a rub during compressor surge calibrations.

Because of the 3rd-stage blade failure in Build 1, part span shrouds were added to these blades in the prototype design; Build 5 of the high compressor rig incorporated these parts in addition to further recambering of the stators. This build was calibrated in June 1966, and its improvement in surge pressure ratio is seen in the comparison to the initial compressor calibration. (See figure 8.) A second test program of this build also substantiated operating the engine with the 3rd- and 7th-stage stators in a fixed position as they are being designed for the prototype engine.

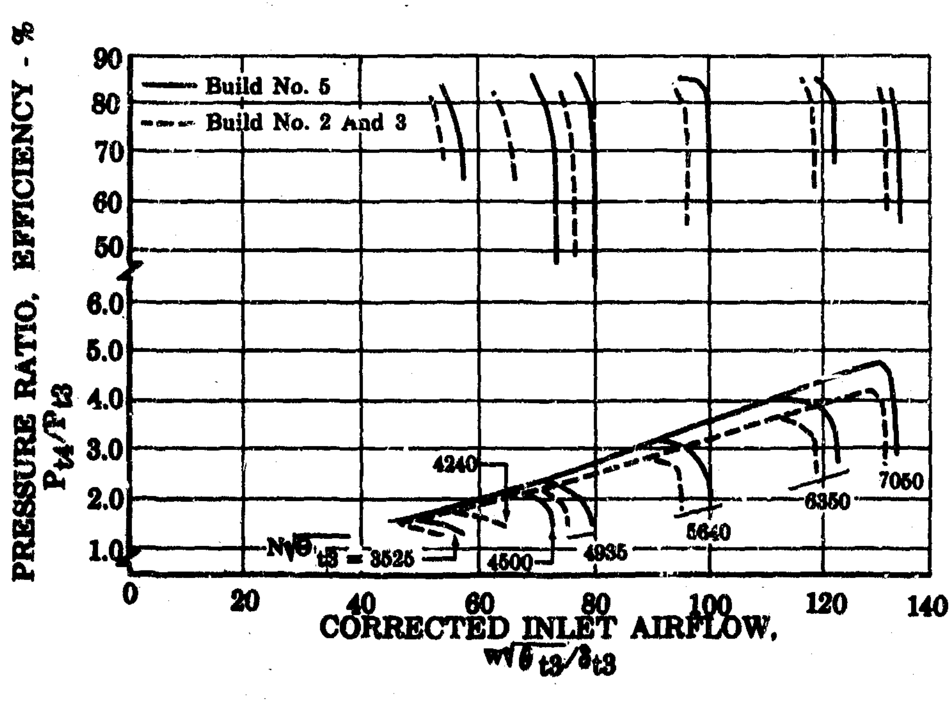

Figure 8. High Pressure Compressor Overall Performance Map Comparison of Build No. 5 With Builds No. 2 and 3

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Although the high speed surge line is below that desired for the prototype engine, the original calibration of the compressor has been improved upon significantly. With the present compressor configuration, the Phase II-C experimental JTF17 engines are matched essentially at the design operating line.

Analysis of the compressor data of Build 2, 3, and 5 has led to a partial redesign of the high compressor to add work to the middle stages. The redesigned blades for stages 5, 6, and 7 are being procured and are scheduled for testing in August. Continued increases in surge pressure ratio are expected to result in adequate high compressor surge margin early in the prototype program.

The high compressor component development program of Phase II-C has provided substantiation for several design changes in the prototype design. Among these items are:

1. A reduction of intermediate case strut losses
2. The incorporation of part-span shroud blades in the third stage
3. Increased clearance between blades and vanes to ensure against rubbing under surge conditions
4. Removal of variable stators from the high compressor
5. Blading design changes to improve wall flow conditions.

The details of these changes are found in the compressor design section.

b. Test Objectives for Phase III

The specific test objectives of the high compressor component development program are to:

1. Achieve an adequate surge margin at all speeds so that the engine will not encounter surge in normal transient or steady-state operation.
2. Improve the efficiency of the compressor so that in combination with the other components the engine will satisfy performance goals throughout the engine operating envelope.
3. Maintain the speed-flow relationship of the compressor to meet SLTO and Mach 2.7 cruise matching requirements.
4. Identify and correct any aeroelastic or mechanical vibration problems in the operating range of the compressor at cruise inlet conditions as well as sea level takeoff.
5. Determine the optimum schedule for inlet guide vane actuation to meet performance requirements.
6. Set the interstage bleed schedule for proper engine acceleration.
7. Determine the effect of the inlet profile on high compressor performance and durability and demonstrate that the required stall margin and efficiency can be met with the fan discharge profile simulated at the high compressor inlet.
8. Develop a compressor discharge profile and Mach number acceptable to the burner section.
9. Demonstrate compressor durability by repeated surges and accumulation of test time.

10. Evaluate compressor disk and blade temperatures during heated inlet steady-state and transient running.
11. Determine the effects of variation in Reynold's number on the performance of the high compressor and overcome any effects as necessary to meet high altitude performance requirements.
12. Analyze test results for substantiation of the design criteria for failed blade containment or disk overspeed margin whenever off-design operation provides the data.
13. Determine high compressor disk life in low cycle fatigue by special tests which accelerate the acquisition of these data.

c. Description of High Pressure Compressor Rigs

Aerodynamic development of the high pressure compressor will be accomplished through an extensive program conducted on compressor rig tests at the Florida Research and Development Center. The full-scale component test rigs will have aerodynamic configurations identical to the JTF17 engine. Variable stators will be used in all stages for initial Phase III testing although only the inlet guide vane will be variable in the prototype engine compressor configuration. This variable inlet guide vane, which also functions as the aerodynamic brake, will be tested in these component rigs as well as in the engine development program. Figures 9 and 10 show the existing Phase II-C high pressure compressor test rig, which will be modified as necessary early in Phase III to match the prototype compressor configuration with its interstage bleed and revised axial spacing. Two additional test rigs will be constructed early in Phase III to meet the development program objectives.

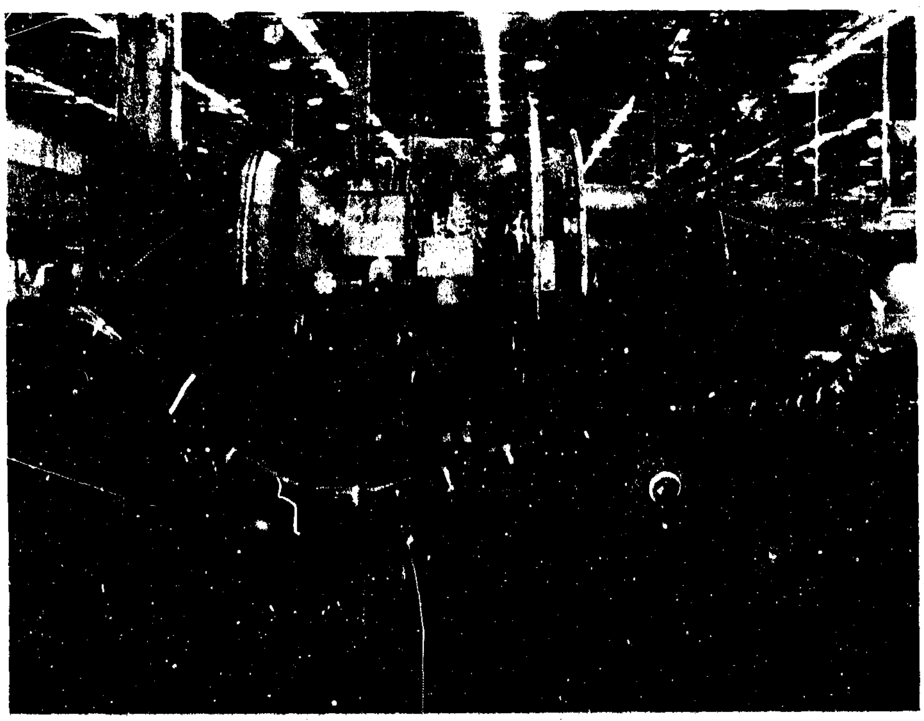

Figure 9. JTF17 Phase II-C High Compressor Rig FE 56925 EII

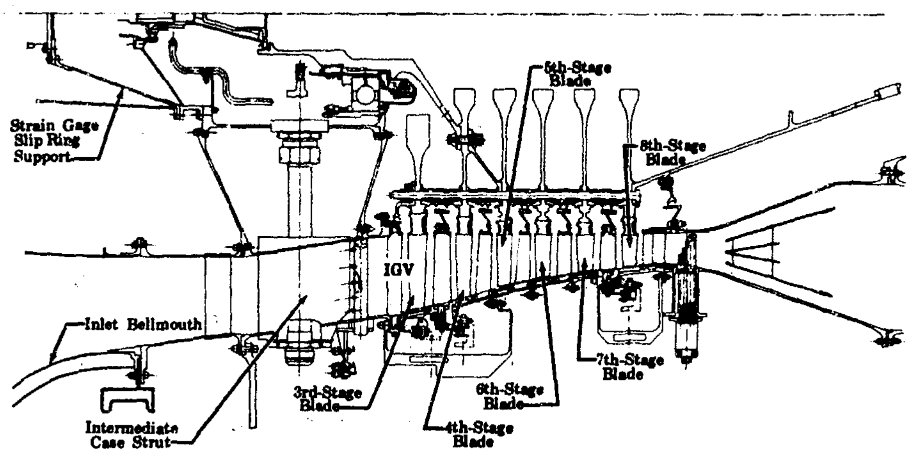

Figure 10. Phase II-C High Compressor Rig FD 16532 EII

(1) Parts Configuration

All rotor assemblies used in the high compressor development program will incorporate standard engine parts and will be directly interchangeable in engine tests. The stator assemblies will also incorporate standard engine parts except where variable stagger vanes are used to provide greater flexibility in selecting an aerodynamic configuration to meet the desired test objective. Support structures must have non-engine parts to adapt the compressor to the test stands. These parts include the intermediate case, diffuser case, driveshaft, nose cone, and bleed and discharge air ducts; although the airflow path entering and leaving the compressor is identical to the engine flow path.

(2) Special Instrumentation

The instrumentation requirements for the high compressor program will vary from build to build depending upon the test objectives. All tests incorporate overall performance instrumentation to measure temperature and pressure at the compressor inlet and discharge stations. The use of engine type probes in these locations in addition to special rig instrumentation will allow direct correlation of rig and engine test data.

(a) Instrumentation of Rotating Parts

For test programs in which stress documentation is required, blade, disk and vane strain gages will record vibratory stresses from natural resonances and aerodynamic excitations. Strain gage locations selected by previous experience and bench tests will assure measurement of the maximum stress in the part. Detailed information of strain gage installation is found in Section II-J (Instrumentation - Strain Gage Section).

Metal temperatures of disks and blades will be measured by thermocouple installations similar to strain gage installations. Disk temperature gradients will be measured to evaluate thermal stress that, along with rotor speed, determines disk low cycle fatigue life.

Strain gage and thermocouple signals are routed out of the compressor through slip rings mounted at the inlet end. The stress levels and vibratory frequencies are monitored on oscilloscopes and recorded on oscillographs and tape recorders. Temperatures are recorded by the stand automatic data recording system.

(b) Interstage Instrumentation

In addition to overall performance evaluation of the compressor, detailed analysis of each stage's performance is required for development of the compressor. Data for this analysis are obtained by interstage measurement of temperature and pressure levels. Thermocouples and total pressure taps are installed on stator vanes, usually at five radial locations, to define stage profiles. Wall static pressures between each airfoil row are also measured for this analysis. Previous experience in JT8D, JT3D, TF30 and other development programs, as well as the performance improvements made during the JTF17 Phase II-C program, shows the effectiveness of this technique for data acquisition.

In special tests when exact measurement of interstage air angles or static pressure profiles is required, banjo, claw, or wedge type probes behind the rotors or stators record these data. Other special instrumentation, such as hot wire probes and subminiature pressure transducers, will be used as required for investigation of internal aerodynamics. Detailed descriptions of this instrumentation may be found in Section II-J (Instrumentation - Traverse Probes and Miniature Pressure Transducer).

(3) Test Facilities

The high compressor rig testing will be accomplished at the Florida Research and Development Center on C-3 and C-7 stands. Test stand requirements for these rigs are:

Rig Inlet Airflow - 130 lb/sec at 14.7 psia
Rig Maximum rpm - 8450 rpm
Maximum Horsepower Required - 20,000 hp
Maximum Rig Pressure Ratio - 6.0
Maximum Rig Inlet Temperature - 700°F

C-3 stand, as currently used in the J58 compressor development program, meets these requirements for all anticipated tests of the JTF17. This test stand is powered by a JT4 turbine modified for operation with steam. It has provided over 3000 hours of reliable development testing in the J58 program. Although C-7 stand will be built primarily for fan rig testing, it will also permit testing of the high compressor rigs with ram inlet pressures up to 40 psia if

this becomes necessary in the development program. Refer to Report B of Volume V (Facilities C-3 and C-7) for detailed information concerning these tests stands.

Data from these test stands are recorded by an automatic data recording system. This system, which is being modified with the construction of C-7 stand, will have the capacity to measure and record 369 channels of data at a rate up to 10,000 samples per second. This type of data recording is particularly valuable to determine compressor performance and operating conditions as surge is being induced. Refer to Report B of Volume V (Facilities - Data Recording) for a more detailed description of this recording system.

d. High Compressor Test Program

High pressure compressor rig tests with rapid feedback of test results into component and engine design and hardware, will develop the compressor to assure the engine an adequate aerodynamic configuration, freedom from destructive resonant or aerodynamic stresses, compatibility with flow profiles to be accepted from the fan discharge, and discharge flow profiles acceptable to the combustor. These tests will be conducted with both sea level ambient temperature and heated inlet air to prove the integrity and capability of the high pressure compressor in all critical areas of the engine flight envelope. The test program, planned for three high pressure compressor test rigs, will utilize the test stands to the fullest extent possible. Test programs are planned to expedite testing to minimize cost per useful data point. As the test program progresses, specific test plans will be altered to concentrate maximum effort upon specific problem areas. The development of the Phase II-C high pressure compressor surge pressure capabilities demonstrated the effects of this concentrated effort.

As improved compressors are developed in the component tests, the most promising configurations will be incorporated in engine tests for further evaluation. The results of these engine tests will be integrated into the high compressor component development to assure compatibility between specific rig test objectives and engine operational requirements.

(1) Category of Tests

High compressor rig testing can be categorized into several types of tests. While more than one type of test may be accomplished on any individual build of a rig, they are described here as separate tests for clarity. All these tests will run with both ambient and heated inlet air temperatures to simulate actual engine conditions in the compressor.

(a) Clean Performance Test (Design Verification Test)

This type of test is normally run with a set of new parts. Minimum instrumentation is installed, usually for overall performance only. This test determines overall performance of the compressor

as it is installed in the engine without the slight penalties associated with instrumentation in the flow path or with reworked airfoils for altered aerodynamics. It measures the advancements made in the development program.

(b) Overall and Stage Performance Test

This test is the principal tool for aerodynamic development of the compressor. Rigs built for this testing have sufficient instrumentation to determine each stage's performance as well as overall performance. Interstage instrumentation, consisting of vane leading edge thermocouples and pressure taps, and wall static pressure taps along the flow path, is used to determine the internal aerodynamic characteristics of the compressor. Calibrations of the rig are run throughout the operational speed range. Variable stators are particularly useful in these tests because of their ability to alter the aerodynamics of the compressor. This essentially allows a calibration of several different compressors in a single rig build and test program.

Data generated in these tests are closely analyzed by design aerodynamic and engine performance analysts. When design modifications are indicated, a coordinated effort managed by the Project Engineer results in its incorporation into hardware at the earliest possible time.

(c) Stress Documentation Test

Strain gage recordings of vibratory stress levels in blades, disks, and stator vanes are the primary objective for this type of test. Sufficient instrumentation is installed to maintain and record the overall performance conditions during the test. These tests are used to develop the mechanical integrity of the compressor to assure engine operation without excessive stress levels. Data from these tests will be used for engine certification requirements to demonstrate acceptable levels of blade and disk vibratory stress. Heated inlet testing is particularly important in this type of test, because only in this manner can naturally resonant and aerodynamically induced stresses be made to occur simultaneously as in engine operation.

All rig tests with variable stators will have strain gages installed for monitoring vibratory stress levels. This is necessary since each adjustment or change of stator position results in a new aerodynamic configuration of the compressor.

(d) Inlet Profile Tolerance Test

This type of test shows the compatibility of the high compressor to accept inlet flow pressure profiles that it would receive from fan discharge with and without the airframe inlet distortion. In this type of test, suitable pressure profile generators will be installed at the inlet to the compressor rig. Figure 11 shows such a profile generator mounted at the compressor rig inlet during a Phase II-C

test program. Testing of this type accomplished in Phase II-C showed no effect on high compressor overall performance or vibratory stress levels, but was conducted to ensure a stress-free operating range for the engine.

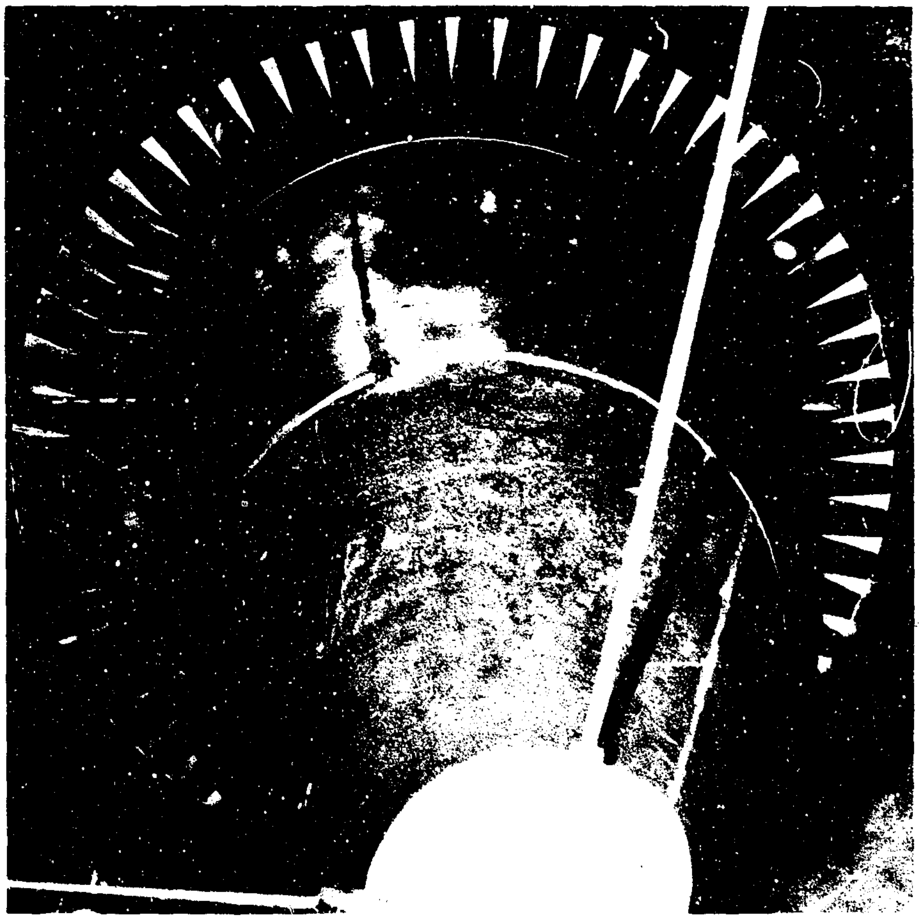

Figure 11. JTF17 High Compressor Inlet in C-3 Test Stand Showing Inlet Profile Generator

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(e) Bleed Schedule Test

These tests will determine the bleed schedule rate required to assure stage matching at start and idle speed conditions of the engine. Several bleed percentage rates at different speeds will be used to determine the best engine settings.

(2) High Compressor Test Sequence

The methods for parts construction, rig assembly, test stand operation, and rig disassembly are similar for all high compressor rig tests. A typical test sequence description relates the steps required to assure a successful build with reliable data for constructive improvements in the compressor development. Figure 12 shows a chronological chart of a build cycle with average times required for each step.

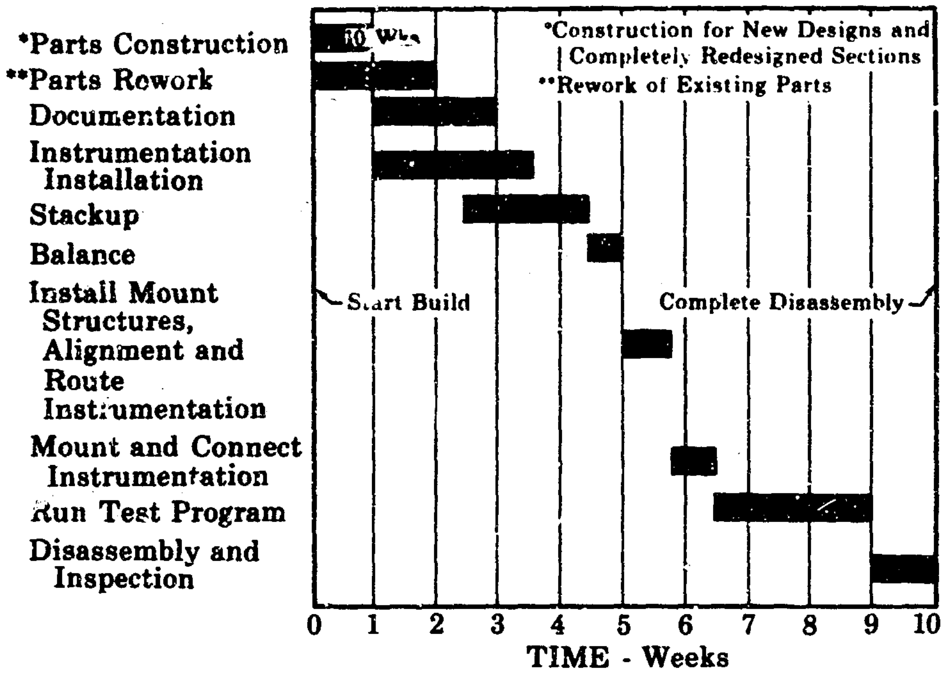

Figure 12. Typical High Compressor Rig Build Sequence Chart FD 16533 EII

(a) Parts Construction

Upon completion of a design layout for a new or redesigned configuration of a compressor section, the raw material for new parts construction is procured to layout dimensions. After raw material and detail blueprints are available, hardware is manufactured for the compressor tests. Inspection of the parts in process and after completion of manufacture ensures correctness to blueprint and accuracy for the intended purpose.

Aerodynamic changes for compressor rig rebuilds are often implemented by reoperating existing parts. This technique allows testing of the change without the long lead times and high cost required for new parts manufacture. Blade and vane airfoil recambering are proven techniques used in the development of all P&WA compressors. Two such recambering operations have been successfully tested in the Phase II-C high pressure compressor on a single set of parts.

(b) Rig Build

Assembly procedures for the high compr... test rig are similar to those required for engine assembly. This includes measurements to ascertain mechanical integrity as well as to document aerodynamic parameters. Rotor snap diameter, running position, platform clearance, oil flow, seal leakage, and dynamic balance measurements are recorded and controlled to ensure that test programs not be delayed by mechanical problems. Documentation of parts and assemblies that affect aerodynamic performance is recorded to ensure the accuracy of the airfoil angles.

Concurrent with the documentation of necessary measurements, instrumentation is installed to acquire data necessary to meet the test objectives. All tests will measure overall compressor performance. Temperature and pressure probes are installed at the air inlet and discharge stations for this purpose.

Instrumentation for full stage performance evaluation consists of thermocouples and pressure taps installed at five radial locations on stator vane leading edges of each stage. This instrumentation is installed in Kiel probes for accurate total pressure and temperature measurement. Small diameter tubing or wire is used for this instrumentation to minimize aerodynamic effects of the installation. Over five years' experience in other P&WA compressor development programs has proven the reliability and accuracy of this instrumentation technique. Typical installations of leading edge vane instrumentation are shown in figure 13.

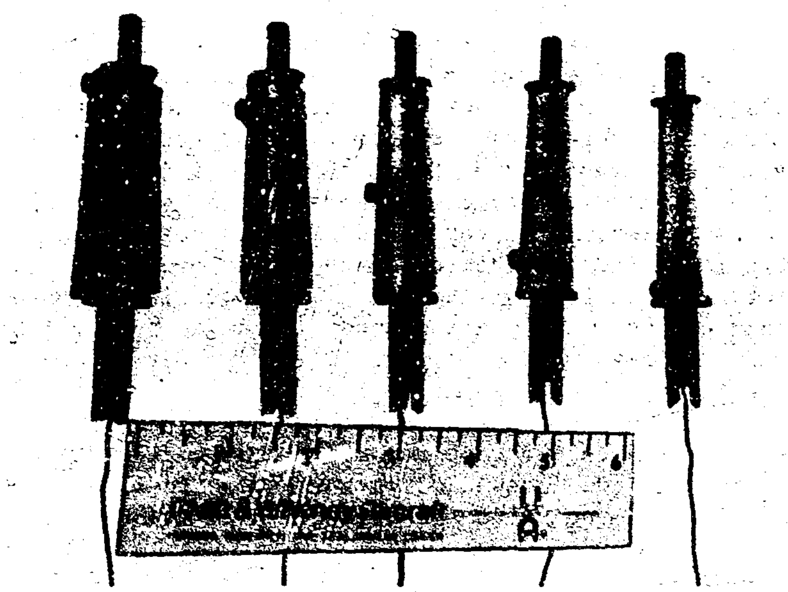

Figure 13. JTF17 High Compressor Stator Leading Edge Interstage Instrumentation FE 59919 EII

Strain gages are installed on blades, vanes, and disks with improved techniques developed in the J58 test program. Phase II-C compressor rig test results with this strain gage technique have been very successful. Performance and stress monitoring programs were completed with approximately 90% of the strain gages functioning even after repeated surges of the compressor.

After measuring and instrumenting the parts, assembly of the compressor can begin. Individual stage rotors are statically balanced before assembly into the stackup. After this assembly is complete, a dynamic balance prevents rig vibration problems caused by rotor unbalance. High compressor unbalance caused no test vibration problems in Phase II-C.

Support cases and bearing compartments are assembled to complete the rig assembly. Oil flow checks and bearing compartment leakage checks assure integrity of these compartments and minimize testing delays by mechanical problems.

After identifying all instrumentation leads and aligning the rig to test stand adapters, it is delivered to the test stand for installation.

(c) Rig Test Operations

After the compressor is installed in the test stand, the drive shaft is connected and the lubrication system is static flowed. Instrumentation systems are calibrated and checked for accuracy. The air inlet duct and connection to rig inlet are checked for leaks to assure accurate airflow measurement. Vibration accelerometers are installed to monitor vibration levels and guard against damage from excessively high levels.

The test program is run at several speed settings, usually six or more, and speed lines generated for a compressor map by varying rig discharge pressure with suitable valves in the exhaust duct. The compressor is surged at least one time for each speed line to determine the compressor surge line. Test conditions are set in the stand control room by monitoring instrumentation samples that are read out in the control room. Rotor speed readings are acquired from permanently installed electronic counters that measure speed from the drive turbine shaft coupling. Rig overspeed is prevented during surges, when the turbine load is abruptly reduced by a quick reacting control valve capable of controlling 10,000 rpm per second accelerations of the turbine.

Because airflow is the most important single parameter for performance analysis, two independent systems measure airflow. Both a standard orifice in the inlet air duct and a calibrated rig bellmouth are used.

(d) Test Data Acquisition

While sufficient instrumentation is used in the control room to set rig test conditions and monitor performance, the bulk of aerodynamic data are recorded by the automatic data recording system. This system has the capability to record all the parameters required for performance analysis of the compressor. These recordings can be made at steady-state operating conditions and transient conditions, as during surge. Performance analysis calculations are then run on a computer in the test area that is coupled to the data recording system. Completed calculations are available at the data center while the test program is in process, usually within three minutes after recording the data. Selected operating parameters for determining overall performance are transmitted to the test stand by teletype for analysis by the Experimental Engineer in charge of the program. More detailed information of this data recording and computing system may be found in Report B of Volume V (Facilities - Data Recording).

Stress survey data are recorded in the test stand by oscillograph and tape recorders connected to strain gages on the compressor rotor by slip rings mounted to the front of the rig. Stator vane strain gage leads are routed directly to amplifiers for the recorders. The strain gage signals are paralleled for visual display on oscilloscopes in the test stand. These visual stress readouts are monitored by the engineer in charge of the test program to avoid operating with excessive stress.

In test programs involving compressors with variable stagger vanes the availability of stage performance data allows on-test-stand selection of stator angles for performance optimization. Strain gage visual display of stress levels shows the effect of these aerodynamic changes. This data feedback results in the capability for intelligent selection of stator settings from the test stand while the test program is in process.

(e) Data Analysis

The high compressor performance is analyzed from plots showing overall performance, individual stage performance, stage radial temperature and pressure profiles, and comparisons of test results to all design parameters.

Overall performance is presented on a compressor map showing speed, airflow, and pressure ratio relationships at constant rotor speeds. (See figure 8) Surge pressure ratio and overall compressor efficiency are also shown on these plots. The initial analysis of data for this map is made by the engineer in the stand as the test program progresses. Computed performance parameters are plotted, usually within three minutes after the data are recorded, to verify the data accuracy and validity. Detailed analysis of the overall performance, including comparisons with previous test results, is accomplished to properly match the high compressor in the engine cycle requirements.

Individual stage performance is analyzed by a number of methods. When compared with previous test results and design parameters, these methods indicate the nature and extent of aerodynamic change required to improve overall compressor performance. The techniques used are:

1. Radial Profile Plot - These plots of temperature and pressure vs radial gas stream location from stator leading edge instrumentation serve as indicators for areas of large aerodynamic distress. These data also are the principal input for all other forms of interstage performance analysis.

2. Phi-Psi (ϕ-ψ) Plot - This is a nondimensionalized plot that has a characteristic curve for functions of stage pressure vs stage corrected airflow for any operating condition. These functions may be defined as follows:

$$\phi = \frac{W\sqrt{\theta}}{\delta} \frac{(N/\sqrt{\theta})_{design}}{(N/\sqrt{\theta})}$$

$$\psi = \frac{P}{P-1} \frac{(N/\sqrt{\theta})^2_{design}}{(N/\sqrt{\theta})^2}$$

where:

W = Airflow

N - rpm

$$\theta = \frac{T_{stage}}{T_{standard\ day}}$$

$$\delta = \frac{P_{stage}}{P_{standard\ day}}$$

P = Pressure

T = Temperature

3. Streamline Analysis - This computer program calculates aerodynamic streamline functions from data for comparisons to design parameters. Airfoil incidence, stage $\Delta P/Q$, relative Mach No. and diffusion factor are calculated at various radial locations for all stages of the compressor.

Of particular importance to test programs involving compressors with variable geometry stators are the radial profile plots and ϕ-ψ calculations that are computed by the test area computer connected to the automatic data recording system. These plots are available while rig tests are in process and are used to direct the test program in a scientific manner by analyzing the performance at each stage immediately as the data are taken. Figure 14 shows sample ϕ-ψ curves and the effects upon stage performance resulting from geometry changes with variable stators. This figure also demonstrates the value of variable geometry stators to the test program. Fixed geometry in a stage results in a single operating characteristic for that stage. However, variable geometry allowing multiple stator configurations results in multiple operating characteristics for that stage; hence this is a useful tool for gaining the most improvement possible in stage performance but must be used judiciously by rapid analysis feedback to avoid running indeterminant parameter tests. A second valuable effect of variable geometry stators is the ability to induce varying

conditions in the airstream entering subsequent stages downstream of the stage being varied. This results in a larger range of operation for the downstream stage and leads to a better analysis of its performance capabilities.

Figure 14 shows typical stage characteristic changes for variable geometry changes. In Stage A, conditions 1, 2, and 3 represent three settings of that stage variable stator. The corresponding effects are shown for Stage B. Varying stage B stators improves the performance of that stage as shown by condition 4.

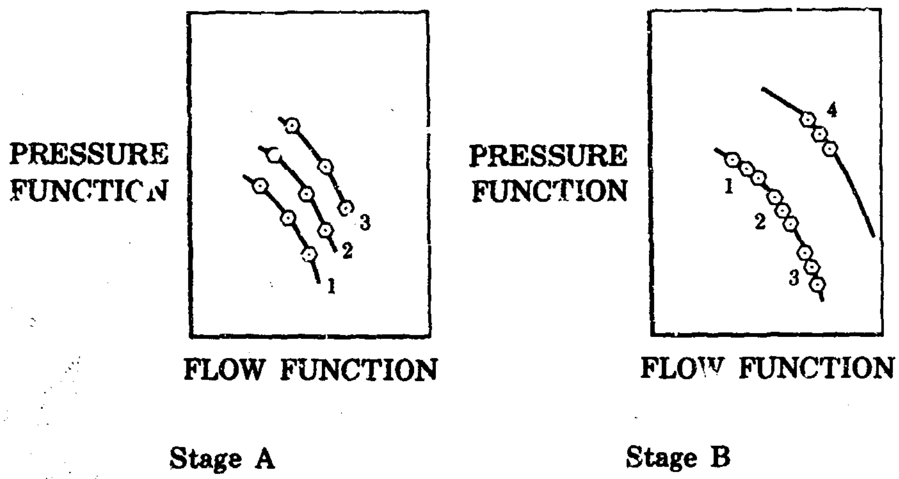

Figure 14. Typical ϕ-ψ Curve for Stage Performance Analysis With Variable Geometry Stators — FD 16534 EII

Stress survey data are analyzed by comparing test results to aeroelastic functions calculated for the design of the compressor. This is shown with plots of recorded stress levels and vibratory frequencies on charts showing compressor rotor speed functions of natural resonances and aeroelastic phenomenon. These data are used to verify that normal operating rotor speeds are free from resonances that may induce excessive stresses in the compressor.

(f) Disassembly

Upon completion of a test program, the compressor rig is disassembled, and all parts are carefully reviewed for any indication of mechanical distress or failure. Critical parts are checked for cracks visually as well as with the latest techniques of magnaflux, Zyglo fluorescent penetrant, or X-ray. Since compressor rigs are subjected to continuous surges in their testing, it is not unusual to find fatigue cracks in the compressor blades caused by the very high stresses encountered during surge conditions.

(g) Rework

After complete inspection of all parts at disassembly, reworks as necessary are initiated to prepare the compressor rig for its next build and test program. These reworks range from small changes for updating the rig with the late design changes not affecting aerodynamics to complete aerodynamic redesigns. Cutting, bending, and rewelding stator vanes have been proven a relatively inexpensive method (dollar-wise and time-wise) for recambering stators by changing airfoil leading and trailing edge angles. Blades are recoined or recambered to alter the aerodynamics of the rotors.

(3) Support for FTS

Prior to the JTF17 FTS test, the high compressor configuration must be selected for the engine to meet the performance and durability goals. This configuration will be thoroughly evaluated in the high compressor rig before being incorporated into the engine.

(4) Design Substantiation Tests

(a) Disk Low Cycle Fatigue Tests

Early in the Phase III program, tests will be run to verify the design criteria for determining low cycle fatigue life of the high compressor disks. Engine disks will be tested in a "Ferris Wheel" rig. This is a test device that simulates operational stresses in a disk and can rapidly accumulate low cycle fatigue cycles. This is accomplished by loading each blade slot with a hydraulic load cylinder and inducing stresses in the disk comparable to those of rotational operation. By cyclically varying these loads, low cycle fatigue testing can be accomplished in a significantly shorter time and more economically than by engine testing. This test rig is shown in the turbine section, figure 61.

e. High Compressor Test Schedule

The high pressure compressor rig test schedule is designed to meet the objectives of the program without delays to the overall engine program. Three test rigs are required to accomplish this program.

The planned tests will minimize the effects of the transition from Phase II-C testing to Phase III testing. Such redesigns as are necessary for the prototype engine compressor will be retrofitted in the Phase II-C high compressor test rig.

Figure 15 shows a schedule of high pressure compressor rig testing planned during Phase III and that projected beyond Phase III to engine certification. The number of rig builds, test time, support activities, and major milestones are shown. Fifty high compressor rig builds will be completed during Phase III, and approximately 2000 hours of test time will be accumulated. The various types of tests, with approximate portions of the total test time are listed below:

1. Clean Performance Test - Five builds will be devoted to clean performance tests and will utilize 150 hours of rig test time.

2. Overall and Stage Performance Test - The remaining 45 builds will develop overall and stage performance using 1330 hours of rig time. These will include:

   Bleed Schedule Tests - Six of the above tests will devote a portion of this program to the determination of the proper bleed schedule rate. Sixty hours of test time will be expended in this effort.

3. Stress Documentation Tests - Ten builds of the high compressor rig will have a portion of their test programs allocated for stress documentation. This will require 100 hours of test time.

4. Inlet Profile Tolerance Test - Twenty test programs will be conducted with inlet pressure profiles similar to fan discharge pressure profiles. Approximately 360 hours will be devoted to this activity.

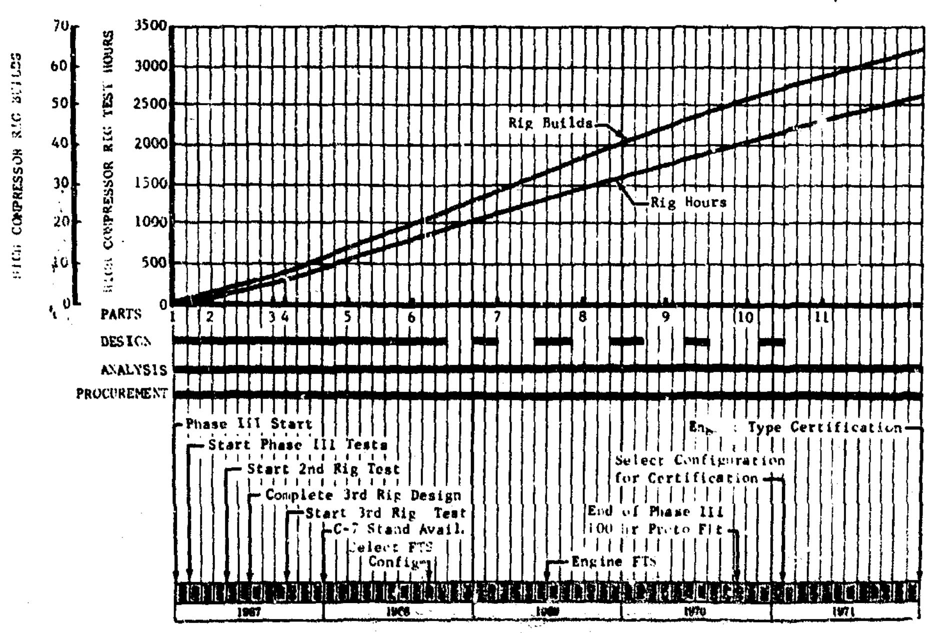

Figure 15. High Compressor Rig Test Program FD 16535 EII

3. Primary Combustor

a. Introduction

(1) Background

An intensive Phase III primary combustor component development program in conjunction with the JTF17 engine development program will include the design, fabrication, and test of all hardware necessary to develop and demonstrate the performance and durability of the combustor to the levels required for successful completion of the JTF17 FTS and the flight test program. Utilization of the modified JT4 engine in Phase II-C has provided an annular rig which demonstrated excellent correlation with Phase II-C experimental engine tests. The high pressure available in this rig provides realistic burner test conditions and an early indication of the combustor durability characteristics. This high pressure was not possible with previous types of burner development rigs. The continued utilization of this modified JT4 engine and the addition of a JFT17 high spool rig for combined testing with the turbine component development program will result in a more comprehensive and realistic primary combustor development program than demonstrated on any previous Pratt & Whitney Aircraft commercial program.

The primary combustor in the JTF17 engine uses the annular ram-induction concept. This ram-induction combustor has demonstrated excellent results in both early research tests and also in the Phase II-C experimental engine tests but must be refined for commercial operation to improve temperature distribution and durability. The combustor employs the efficient use of the velocity head of air to create a turbulent combustion zone rather than diffusing the air to a high static pressure and then reaccelerating it through holes as is done in more conventional burners. This state-of-the-art development has resulted in a short and lightweight combustion section without sacrificing important performance requirements. The requirements of exit temperature profile, combustion efficiency, pressure drop, short length, high fuel turndown ratio, low smoke generation, acceptance of inlet airflow changes, and durability are reviewed in the primary combustor performance section Volume III, Report A, Section IIIB, and the primary combustor design section, Volume III, Report B, Section IIB.

(2) State-of-the-Art

The ram-induction combustor proposed in the JFT17 engine is a state-of-the-art improvement resulting from advanced research programs started at FRDC in 1963. The short combustion length and the uniform discharge temperature distribution demonstrated by the early tests resulted in the decision to incorporate the ram-induction combustor in the initial experimental JTF17 engine.

The ram-induction burner differs from a conventional can-annular or annular burner by introducing air into the combustion region with efficient turning vanes which capture the required proportion of airflow, utilizing the velocity head for turbulent combustion instead of relying on static pressure drop. The pressure loss and length usually associated with the low velocity part of the engine diffuser are eliminated in the ram induction combustor by using a short, efficient diffuser of low area ratio to partially diffuse the air. This air, which is still at a relatively high velocity, provides the energy to promote mixing after being turned into the combustion zone. The high velocity air over the exterior of the combustor walls provides a high heat transfer coefficient to reduce metal temperatures and eliminates the extreme temperature gradients that cause the thermal fatigue often encountered with less efficiently cooled burners. The annular configuration eliminates all cross over tube and tangency problems that have resulted in burner distress and nonuniform turbine inlet temperature distribution encountered with can-annular burners. The full annular arrangement permits a greatly simplified transition section which will reduce cost and increase reliability. The reduced diffusion rate, ram-induction characteristics, and the annular configuration all contribute to making the combustor more insensitive to compressor discharge flow profile changes.

(3) Phase II-C Status

The primary combustor achieved the objectives of Phase II-C early in the program. The most significant of these objectives was the demonstration of the ability to operate a JTF17 engine with a "ram-induction" main combustor. Combustor ignition, stability through the starting range, performance, and temperature distribution met all the goals for the Phase II-C operation of the experimental JTF17 engine. However, it was recognized that further development would be required to achieve combustor durability and refine the temperature distribution to obtain maximum turbine life. The success of the ram-induction principle indicates that this type of primary combustor can be developed to meet the prototype requirements.

By January 1966, the primary combustor had demonstrated combustion efficiencies greater than 99.0% and a pressure loss of less than 5.7%, as measured in the modified JF4 engine. Stability was demonstrated by the ease of sea level ignition and acceleration in the starting region on both the JT4 and the JTF17. In the short time period of the Phase II-C program, the discharge temperature distribution has been developed to the level of the current JT4 commercial engines.

In the evaluation of the primary combustor exit temperature distribution patterns, several numerical parameters are used. These are: (ΔTVR), (d_{max}), and ($d_{r\ max}$). ΔTVR is a useful parameter for early evaluation of data. However, it is not considered as the definitive parameter as it compares measured data with an average temperature whereas the most desirable turbine inlet profile is not necessarily flat. The d_{max} parameter has been established to reflect a comparison

of the peak temperature with the desired turbine inlet profile. For evaluation of the primary combustor temperature distribution on the first turbine blades, $d_{r\ max}$ has been established as defined below.

ΔTVR - the ratio between the temperature rise at the highest individual point in the exit distribution and the average overall temperature rise. (A gross indication of overall acceptability and a definitive indication for vane coating life).

d_{max} - the maximum positive difference between the measured individual temperature at any radial point and the desired circumferential average at the same radius expressed as a percentage of the desired temperature rise at that radius. (A definitive indication of local temperature for vane life).

$d_{r\ max}$ - the maximum positive difference between the measured and the desired circumferential average temperatures expressed as a percentage of the desired temperature rise at that radius. (A definitive indication for temperature profile for blade life).

Examples of the points defined by these parameters are shown on figure 16.

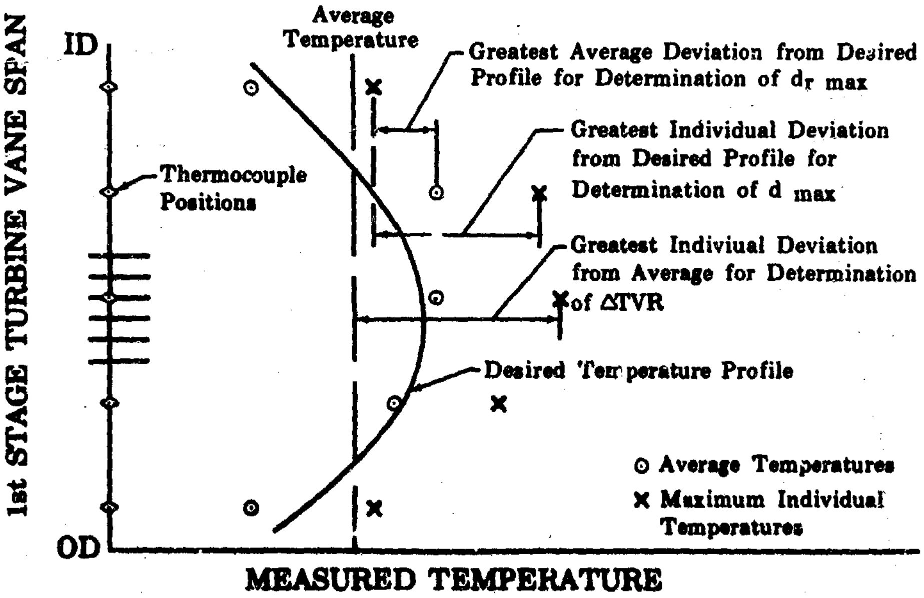

Figure 16. Combustor Exit Temperature Distribution Example FD 17017 EII

The modified JT4 engine has shown excellent correlation with the initial engine experimental test data as shown in table 5.

Table 5. Correlation of Rig Data

Engine	Primary Combustor Configuration	Vane Average Temperature, °F	ΔTVR	d_{max}	$d_{r\ max}$
JT4	Mod 5-1M	1901	1.28	26.5	4.4
JT4	Mod 5-1N (last)	1904	1.25	23.6	3.1
Initial Engine	Mod 5-1P (first)	1923	1.27	28.7	4.5

Additional details on the demonstrated performance of the primary combustor are covered in Vol. III, Report A, Section IIIB.

Revisions for the JTF17 primary combustor as the result of Phase II-C testing will include:

(1) A shorter diffuser to reduce the combustion section length without reducing the length of the combustion zone, (2) reduced weight by supporting the combustor from the combustion chamber cases instead of an extra annular shell, (3) a simplified diffuser deflector for improved airflow control and cleaner combustion, (4) module construction for improved maintainability and greater development versatility, (5) simplified combustor detail construction for reduced fabrication and parts costs, (6) increased primary airflow to reduce carbon and smoke formation, and (7) the scoop revisions for improved cooling and reduced metal temperatures.

The 120 degree segment and the annular combustion test rigs will require revisions to accept this revised configuration during Phase III, although features and principles of the prototype configuration can be evaluated while the modifying hardware is being fabricated.

b. Test Objectives for Phase III

The primary combustor component test objective for Phase III will be the development of a configuration suitable for the FTS engine and the flight test program by combining performance advantages relative to efficiency, pressure loss, temperature distribution, ignition, and stability with freedom from distortion, burning, cracking, and carbon accumulation. The specific objectives for the primary combustor component testing are the following:

1. Develop the exit temperature distribution to meet the desired turbine inlet profile, $d_{max} = 10\%$.
2. Maintain the demonstrated performance efficiency over 99.0%.
3. Maintain the demonstrated pressure loss at SLTO.
4. Develop the altitude relight characteristics to meet the relight envelope.
5. Develop the durability and reliability required for successful completion of the FTS and flight test program.
6. Low smoke generation and freedom from carbon accumulation.

7. Develop the fuel nozzles for required performance at maximum fuel and ambient temperature conditions.
8. Test reduced weight configurations for acceptable durability and performance.
9. Test reduced cost configurations for acceptable durability and performance.

c. Test Rig Descriptions

The test rig descriptions will include three segment rigs, two annular rigs, and reference to the support given to the engine test section. The segment rigs will cover two 120° rigs and one 30° rig. The annular rigs will cover the modified JT4 engine and a JTF17 high rotor assembly referred to as the high spool rig.

(1) Segment Rigs

Early in the Phase III primary combustor program, a 120° segment rig will be utilized in its present experimental engine configuration, and then in the prototype configuration to duplicate the engine hardware. Figure 17 shows the 120° segment rig mounted in A-11 test stand. This rig is a full-scale cross section of the primary combustor from the diffuser inlet to the transition duct discharge. The diffuser wall contour and the inner and outer cases simulate the experimental JTF17 engine. The inlet to the rig includes a heater burner to raise the inlet temperature to the engine compressor discharge level, a plenum chamber, and a straight approach section to the diffuser inlet. In the approach section, the airflow profile may tailored to the desired configuration.

Figure 17. 120-Degree Segment Rig Installation on A-11 Stand — FE 54006 EII

The rig instrumentation includes: (1) an airflow measuring venturi upstream of the heater burner, (2) rig inlet pressure and temperatures, and (3) a combustor discharge pressure and temperature rake. The discharge rake is platinum-tipped to withstand the high rig discharge temperature, and it swings to traverse the complete rig exit.

The prototype engine configuration will require the addition of a second 120° segment rig with the shorter primary diffuser section. This rig will be constructed to permit testing at higher pressures. When fabrication of this second rig is completed, the Phase II-C rig will be retired.

A second segment rig, simulating approximately 30 degrees, will be added to the program early in Phase III to demonstrate the capability of the fuel nozzles to operate with currently available aviation kerosene at the temperatures expected in the engine. This rig will be installed in a round duct to permit operation at higher pressures to more closely simulate the actual nozzle and support assembly environment.

(2) Annular Rigs

Annular primary combustor rigs permit closer simulation of the exact engine configuration and permit evaluation of combustor changes by observing the overall repeatability of a pattern versus the local areas observed in a segment rig. Full-scale combustor components will be used in the JT4 engine annular rig used in Phase II-C and in a JTF17 high spool rig for integrated programs with high compressor and turbine development during Phase III. Test hardware that demonstrates satisfactory performance in these rigs will be interchangeable with the prototype JTF17 engine for continued testing.

(a) Modified JT4

The first of these annular rigs is a modified JT4 engine, which is shown in figure 18 on a sea level test stand during Phase II-C. The burner section of the JT4 was reoperated to a full-scale primary combustor section of the initial experimental JTF17 by adding a 10.5-inch extension in the JT4 diffuser to duplicate the wall contours and the 12 struts in the experimental engine. The test rig also contained the experimental engine diffuser-deflector, primary combustor and fuel nozzle and support assemblies, and the fuel plumbing manifold (figure 19). The inner and outer combustor cases were replaced and a special transition has been adapted to the smaller diameter turbine. The rig is ideal for testing of the primary combustor at high pressures that could not be obtained except by testing the complete engine. The primary combustor inlet conditions in the JT4 engine are: pressure = 176 psia, temperature = 730°F, and airflow = 256 lb/sec, compared with the prototype engine sea level conditions of 180.7 psia, 717°F and 289.5 lb/sec.

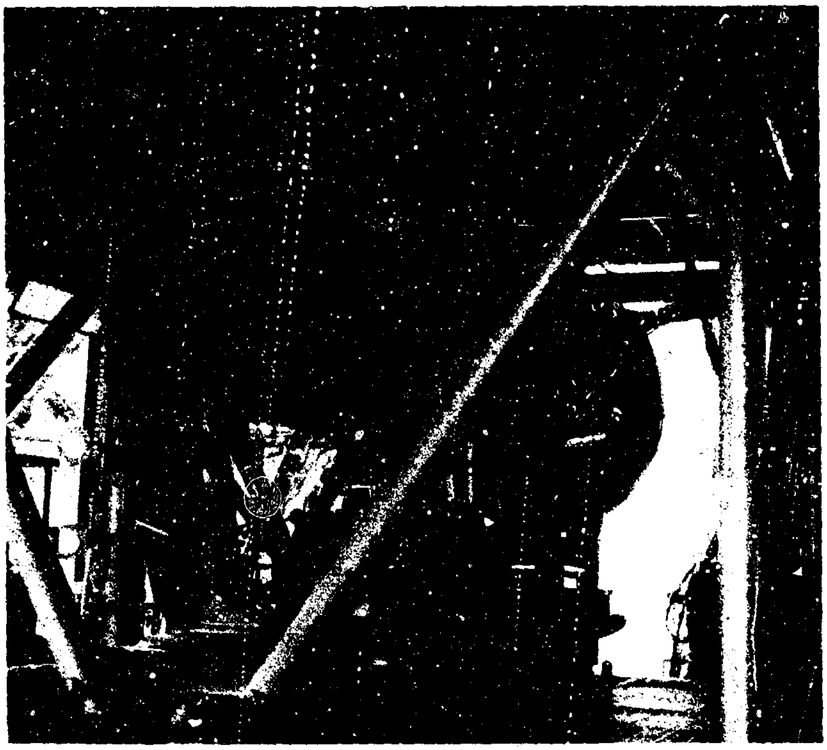

Figure 18. Annular Primary Combustor Rig (Reoperated JT4) on Test

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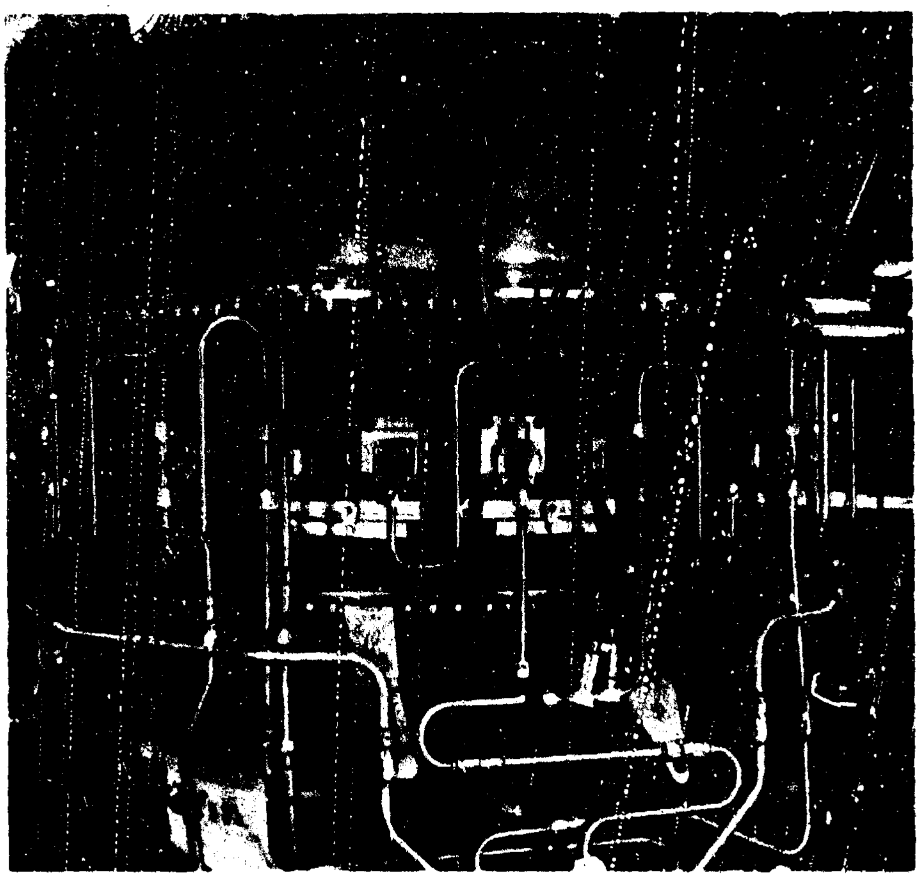

Figure 19. Annular Primary Combustor Rig

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The primary combustor inlet conditions are measured by fixed pressure and temperature instrumentation in the leading edges of the diffuser adapter struts. The combustor section discharge pattern is measured by 5 thermocouples on each of 40 vanes, as shown in figure 20. One of two additional vanes, each having 5 pressures, to measure the combustor section discharge total pressure is also shown in figure 20. This instrumentation is shown in a test stand installation in figure 18.

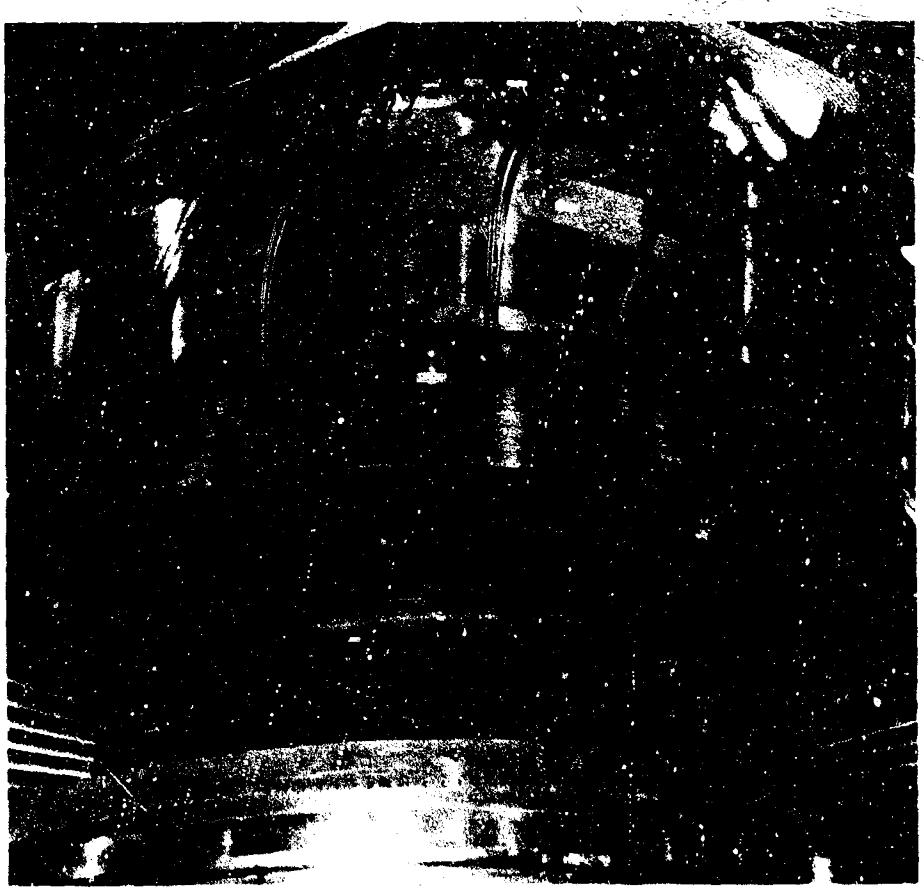

Figure 20. Annular Primary Combustor Rig Discharge Instrumentation FE 55022 EII

(b) Turbine High Spool Rig

The high spool rig described in Section IID of this report is scheduled for July 1967 to permit combined testing with the turbine development. This rig will consist of the high rotor assembly of the JTF17 engine. The high primary combustor discharge temperatures required for the turbine development will make this a valuable rig for development of the desired exit temperature distribution. Further details of this rig configuration, instrumentation, and facilities are given in this Report, Section IV, Turbine.

(c) JTF17 Engine

Development of the primary combustor by early testing on full scale component rigs provides for rapid evaluation of configuration changes and design developments to supplement the engine test program. The configurations with the greatest potential will be incorporated in instrumented engines for continued testing at sea level and altitude. These engines will incorporate the same type first-stage turbine nozzle vane instrumentation for the measurement of temperature distribution and pressure. This will be done with vane instrumentation, as shown in figure 21. For additional information on this testing refer to the engine test section, Vol. III, Report E, Section III.

Figure 21. 1st-Stage Turbine Vane Showing Instrumentation — FE 57744 EII

d. Support Equipment

The primary combustor development program will be supported by additional test benches and water table facility.

(1) Flow Test Benches

The flow bench for the fuel nozzle and support assemblies will permit checking of new assemblies to confirm their acceptability. By rechecking the fuel flow schedule and monitoring engine and rig operation, the repeatability and durability of the nozzles will be substantiated. The flow chamber for the test bench will accept nozzle and support assemblies for both the primary combustor and the duct heater. This flow chamber allows observation of the nozzle spray quality, and the spray angle can be measured by a direct reading protractor in the chamber as shown in figure 22. Additional instrumentation will provide for the measurement of fuel flow, pressure, and temperature. The bench and spray chamber are shown in figure 23.

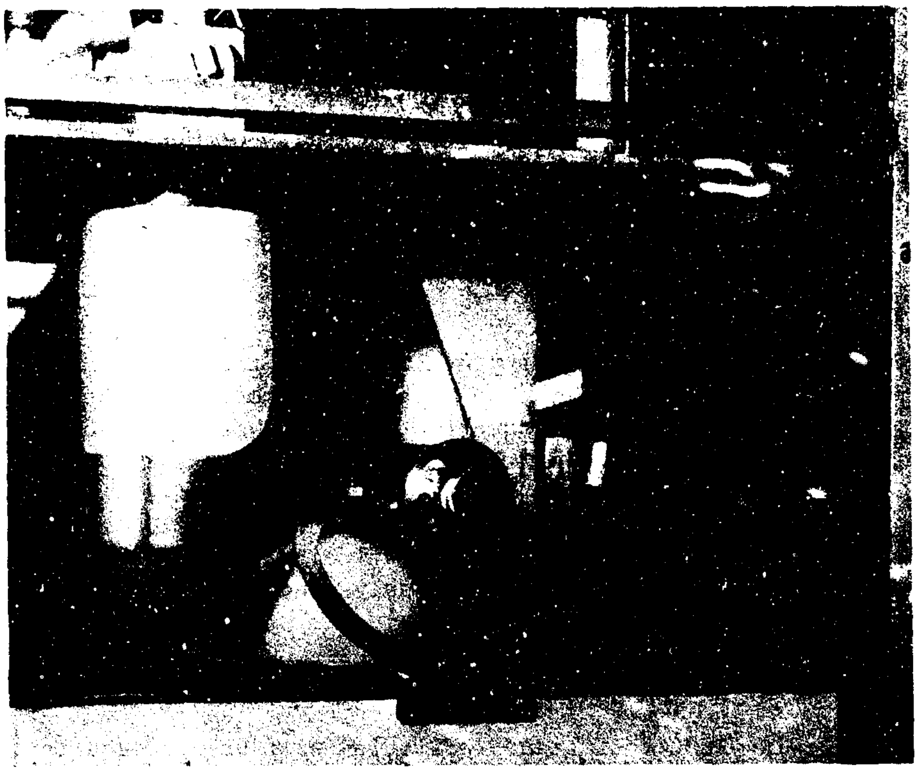

Figure 22. Fuel Nozzle and Support Spray Chamber FC 12273 EII

Figure 23. Fuel Nozzle and Support Test Bench and Spray Chamber FC 12275 EII

A flow bench of higher capacity will be used to check the fuel distribution of the nozzle and support assemblies by testing groups of nozzles in combination with the fuel manifolds. This testing will be required to determine the size and configuration of plumbing that will ensure uniform flow distribution. The uniformity of the distribution can be determined by measuring the supplied pressure to each fuel nozzle while testing over the operating range of the system.

(2) Water Table

The water table (figure 24) is a rig that permits a hydraulic analogy to be made for preliminary evaluation of the flow characteristics in the primary combustor. Two-dimensional models can be fabricated quickly and inexpensively from sheet metal and plastic. Contour changes may even be obtained by using clay. These tests can be conducted best by probing with a hypodermic tube flowing dye at a constant rate. The direction and velocity of the dye flow will provide an indication of the airflow path, velocity, disturbances, and recirculation. A typical water table analysis of the JTF17 primary combustor may be seen in figure 25.

e. Facilities

The following FRDC test stand facilities will be utilized in the JTF17 primary combustor development program. Segment rigs will use test stands A-11, B-2, C-1, D-10, D-26, and DM-42. The annular rig will be tested in stand A-3 or A-4 in addition to the JTF17 engine stands described in the engine test section Vol. III, Report E, Section III.

(1) Test Stands A-3 and A-4

Test stands A-3 and A-4 are existing sea level test stands with the following capabilities:

1. Thrust measuring system upper limit 60,000 pounds.
2. Instrumentation consists of centrally located automatic data recording and processing equipment with 185 channels of steady-state pressure recording, 160 channels of temperature recording, 6 channels of low and/or high speed, 12 channels of vibration recording, and 40 miscellaneous channels (thrust position, traversing, transient, etc.). Most of these channels are also reproduced in the control room for test personnel observation. In addition, there are 35 channels of control instrumentation from stand to control room.
3. Compressed air at a rate of 3 lb/sec at 80 psig is available for engine starting and motoring.
4. Jet fuel can be pumped at ambient temperature at a rate of 140,000 lb/hr to the test engine. Three fuel systems are available.

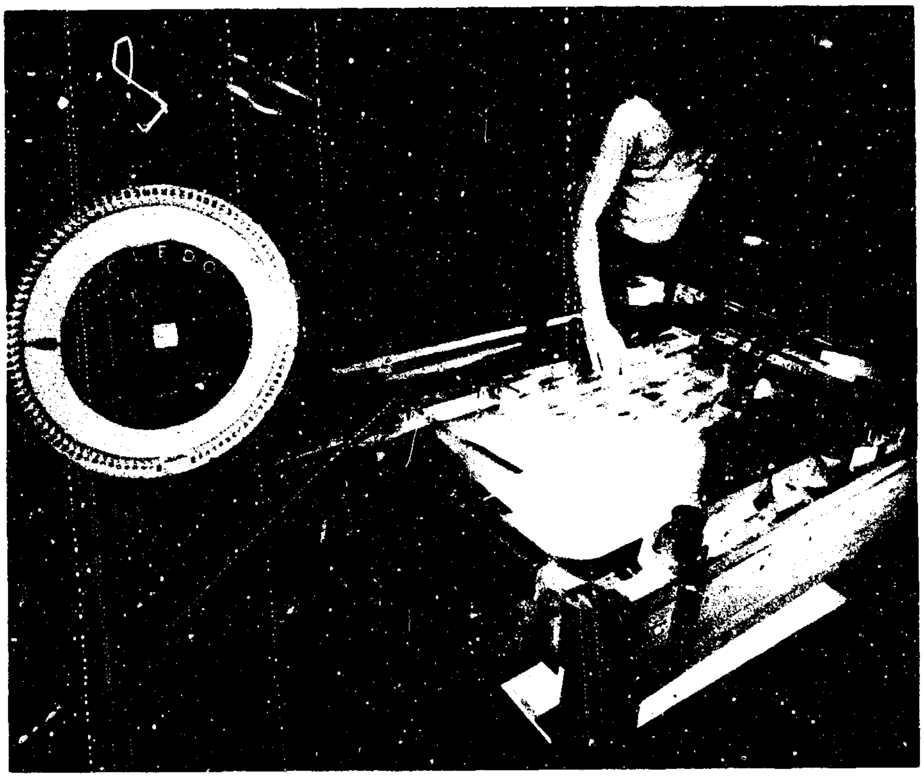

Figure 24. Water Table Rig D-26 FE 49325 EII

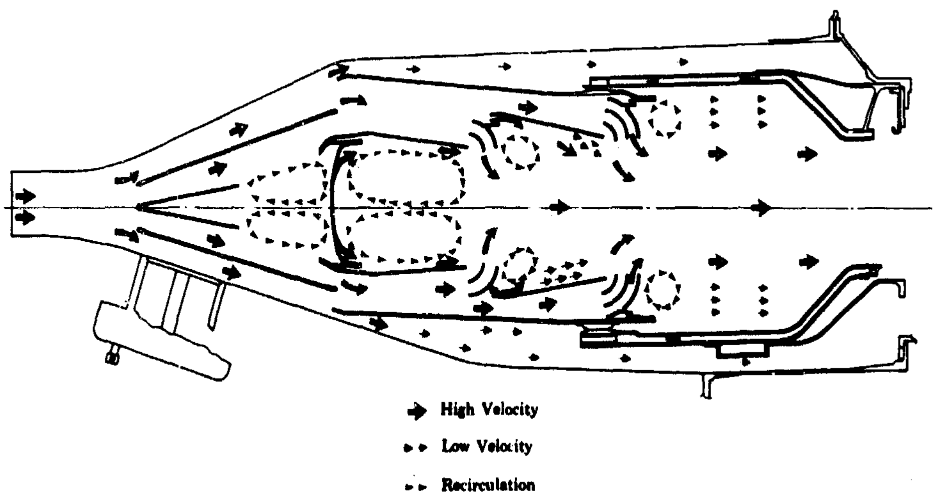

Figure 25. Water Table Analysis of the Primary Combustor Airflow FD 13451E EII

(2) Test Stand A-11

Test stand A-11 is an existing test stand for primary combustor and fuel nozzle test rigs, as shown on the schematic in figure 26, with the following capabilities:

1. Air supply to rig is ducted from J57 jet engine exhaust having a capability of 160 lb/sec at approximately 900°F.
2. Heated fuel system capable of 000 lb/hr at 500°F temperature.
3. Compressor bleed air from J57 can be utilized, to a maximum of 9 lb/sec at 450°F.

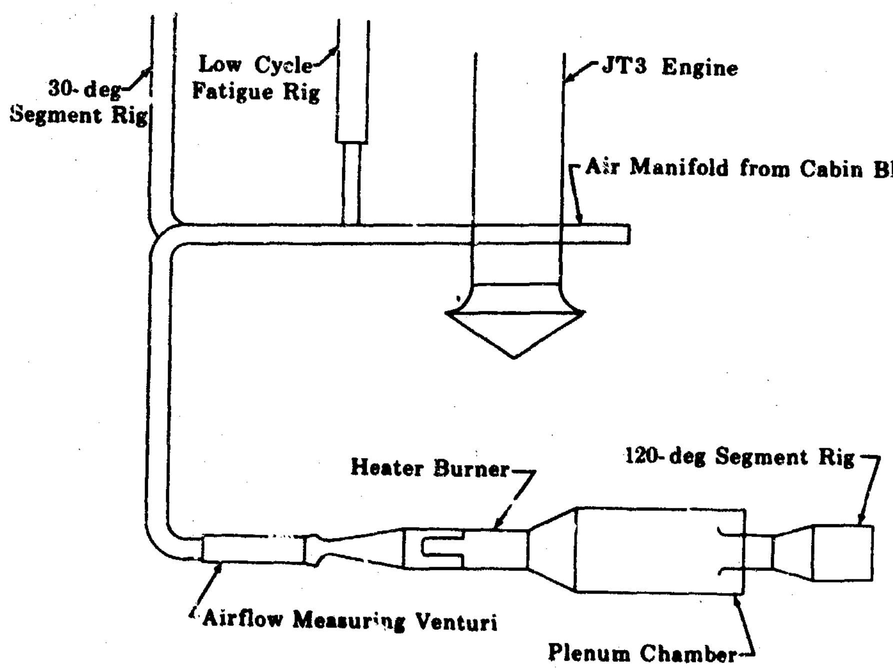

Figure 26. A-11 Test Stand Schematic FD 16528 EII

(3) Test Stand C-1

Test stand C-1 is an airflow and burner test stand as shown on the schematic in figure 27, with the following capabilities:

1. Airflow: 8 lb/sec at 63 in. HgA
100 lb/sec at 120 in. HgA
24 lb/sec at 180 in. HgA

2. Air temperature: to 900°F at 20 lb/sec (non-vitiated)
   to 2000°F at 20 lb/sec (vitiated)
3. Exhauster operation to 4.2 in. HgA at 5 lb/sec
4. Jet fuel flow to 5000 lb/hr, 500 psig, and 500°F

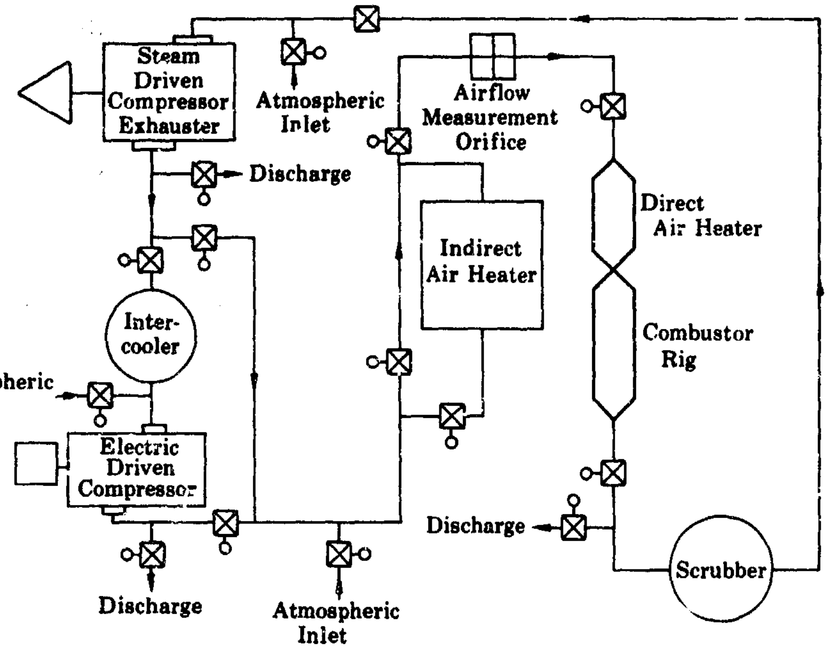

Figure 27. C-1 Test Stand Schematic — FD 16529 EII

(4) Test Stand D-10

Test stand D-10 is a high flow static test bench for testing fuel system components and air turbine-driven pumps and controls with the following capabilities:

1. Fuel supply: 100,000 lb/hr at 1000 psi and 150°F maximum, either clean or with contaminant injection. Open or closed loop.
2. Air supply: 4.2 lb/sec at 375 psi and 400°F.

(5) Test Stand D-26

Test stand D-26 is a water table test bench with the following capabilities:

1. General purposes: flow bench with minimum disturbance dye injection, and both visual and photographic capabilities.
2. Water supply: velocity up to 25 ft/sec at a maximum water height of 1.5 in.

(6) Test Stand DM-42

Test stand DM-42 is a fuel nozzle calibration bench test stand with the following capability: Fuel supply: 4000 lb/hr at 1000 psi and 80°F. The spray chamber is equipped with a spray angle protractor.

f. Phase III Test Program

The primary combustor component test program is planned to obtain the maximum development of the annular ram-induction configuration through utilization of segment rigs, annular rigs, and JTF17 engine tests. The objective of this test program has been defined as the development of a primary combustor suitable for the FTS engine and the flight test program.

The Phase II-C status has shown that the primary combustor already demonstrated the important characteristics of combustion efficiency and pressure drop. Substantial progress has also been made in meeting the temperature distribution and durability goals. The ability to successfully apply rig test data to engine hardware will result in a Phase III test program to develop a primary combustor that meets or exceeds all of the combustor objectives for the JTF17 engine. In addition to providing data on the individual components performance, rig testing indicates the areas that require additional development effort. The rig programs will permit testing of several different configurations in the same time span that it would normally take to test one configuration in the prototype engine. These test programs will assist the selection of the configurations for engine test.

The majority of configuration changes made to solve a significant development problem influence other parameters. For this reason, performance and durability objectives cannot be completely separated, and tests to investigate specific areas will provide additional test data and knowledge in other regions. For example, local revisions in a component may be tested while other areas of the same component remain unchanged, and substantiating test time will be accumulated to evaluate durability. This will require careful evaluation because of the large number of configurations and combustors tested in a development program.

(1) Segment Rigs

The primary combustor rig inlet pressure profile will be tailored to the measured profile of the high compressor to determine the compressor influence on the primary combustor section. The rig results are based on the data taken in the center 60-degree segment to eliminate side wall effects. This segment is acceptable for evaluation of a primary combustor configuration because it includes two diffuser strut passages, four fuel nozzles, and four repeating wall scoop patterns.

The prototype engine configuration will require changes in the 120-degree rig cross section contour to exactly duplicate the shorter primary diffuser section. At the same time, a rig will be constructed to permit testing at higher pressures. Programs will continue on this rig to evaluate pressure loss, efficiency comparisons, component metal temperatures and discharge temperature distribution patterns for the primary combustor influence on the turbine. In addition to these programs, the rig will also be used to investigate the altitude relight capability of the primary combustor and the hot fuel performance of the fuel nozzles.

The 30° segment rig will be used to demonstrate the capability of the fuel nozzles to operate with the selected fuels at the maximum temperatures expected in the JTF17 engine. These tests will be important in demonstrating the advantages of the nozzle metering system chosen for continued development. This dual orifice, variable secondary nozzle has already demonstrated a significant advantage over other methods when tested in a J58 burner rig with the currently available aviation kerosene at conditions more severe than those anticipated in the prototype JTF17 environment.

(2) Annular Rigs

The modified JT4 engine will continue to be used in its experimental engine configuration to evaluate concepts of the prototype engine while revised adapting hardware is being designed and fabricated to modify it to the shorter primary diffuser section. The primary combustor development program will be continued on this rig until 1 July 1968 to demonstrate the performance and durability of the prototype configuration.

The high spool rig programs will provide combined testing with the turbine component development program. The high primary combustor discharge temperatures required for the turbine development will assist in the development of the primary combustor exit temperature distribution and it will provide an indication of the effect of combustor temperature rise on hardware durability. Combustor programs on this rig will include tests of front end air wash configurations to develop clean burning designs for low smoke generation and to prevent the accumulation of carbon deposits which would result in turbine blade erosion. Early development of the desired turbine inlet profile will be a requirement to permit realistic testing for the turbine. The goal for temperature distribution is d_{max} = 10%. This parameter compares the maximum individual measured deviation with the average desired temperature profile. Definitions for this and other comparison parameters are in paragraph 3(a)(3) preceding.

(3) JTF17 Engines

By July 1968, the primary combustor will be developed to a point where the temperature limitation of the JT4 test rig will prevent distinguishing between design revision changes relative to the durability and life of the component parts. The annular combustor testing will be continued on JTF17 engine programs with support from the segment rigs and the high spool rig. For additional information on this sea level

and altitude program refer to the engine test, Vol. III, Report E, Section III. Attainment of the primary combustor goal will be based on demonstration of durability in the engine and the demonstration of the desired temperature distribution based on the turbine performance and durability. Because of the interdependence of each engine component, the changing configurations in other sections, and the changes in the primary combustor, will require that all parameters continue to be reinvestigated to ensure the best combination of performance and durability features.

g. Primary Combustor Test Schedule

The schedule for the primary combustor Phase III test program is summarized in figure 28. This testing will include segment rigs, water table analogy, component support flow benches, annular rigs, and engines. All tests will be conducted with full-scale components, and the parts on the annular rigs will be interchangeable with the prototype JTF17 engine.

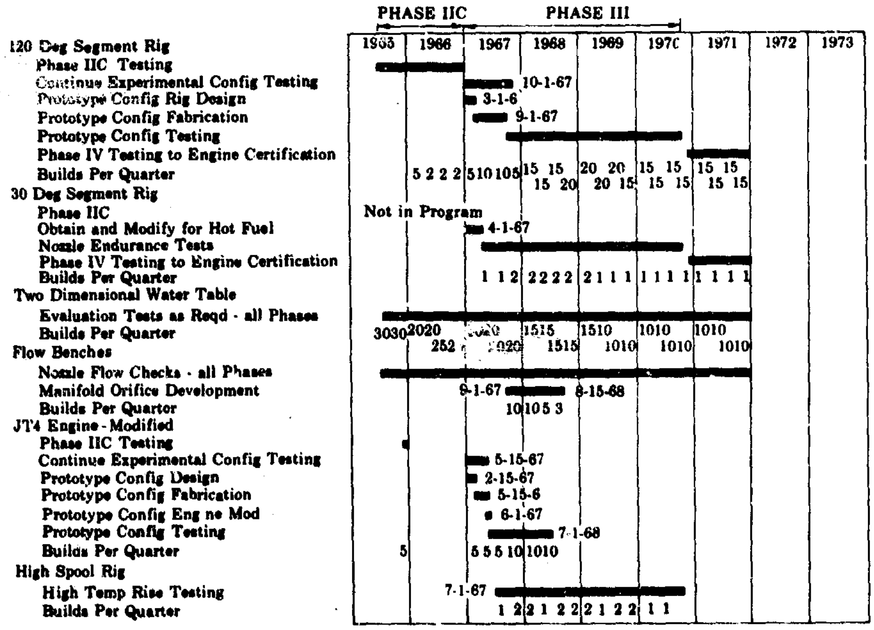

Figure 28. Primary Combustor Test Rig FD 16490
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The primary combustor development during Phase III will continue with evaluation of prototype features and design concepts from the early experimental 120 degree rig and annular rig configurations. During this same period, the rigs will be converted to the prototype JTF17 configuration. Most of the water table evaluation tests will be completed for the prototype configuration during the Phase II-C. The rig will continue to be used as an aid in interpreting changes and effects on an "as required" basis.

Fuel nozzles have been checked on a flow bench to determine the acceptability of redesigned nozzle and support assemblies, and periodic rechecks have been made to ensure repeatability. This program will continue throughout Phase III. Manifolds and nozzle and support assemblies will be flow checked to determine the size and configuration of plumbing that will be required to ensure uniform fuel distribution. Experience gained from the J58 program has provided confidence in the fuel nozzle operation at high temperatures. This will be confirmed early in the Phase III program by endurance testing with hot fuel in a hot environment on a segment rig.

By the middle of 1968, the temperature rise limitation of the annular JT4 rig will require that the sea level performance and durability program be combined with an experimental prototype JTF17 engine for the remainder of Phase III. During this later time period, a second prototype engine will be used to evaluate the altitude performance and confirm the relight capabilities of the primary combustor configuration. The rapid progress of the Phase II-C primary combustor development could lead to an optimistic approach but it must be emphasized that as development of the burner and the engine progresses, the changing configuration will demand that all parameters be reinvestigated to ensure the best combination of performance and durability.

By July 1967, the primary combustor testing will be combined with the turbine development in a high spool rig. The ability of this rig to produce high temperature rises will assist in the evaluation of the temperature distribution, durability, and clean burning characteristics of the primary combustor. Attainment of the combustor temperature distribution goal will be demonstrated by satisfactory turbine performance and durability in the prototype JTF17 engine.

Component testing in the primary combustor development will accumulate approximately 17,100 hours during the Phase III program. Figures 29 and 30 show the breakdown of this test activity. Approximately 6,800 hrs will be segment rig testing with 5,100 hrs for fuel nozzle development and hot fuel endurance. Annular combustor testing will be approximately 2100 hrs divided between the JT4 engine and the turbine high spool rig. The remaining hours will be used for component flow bench support for fuel nozzle and manifold testing.

h. Phase IV Engine Certification

The Phase IV primary combustor component development program will include design refinements and testing to develop and demonstrate the performance and durability for successful completion of the JTF17 type-certification program. This program will be a natural progression of the Phase III testing in segment rigs, annular rigs, and prototype JTF17 engines along with component support test benches. The component rig testing in the primary combustor development program will accumulate approximately 7,000 additional hours during Phase IV before Engine Certification.

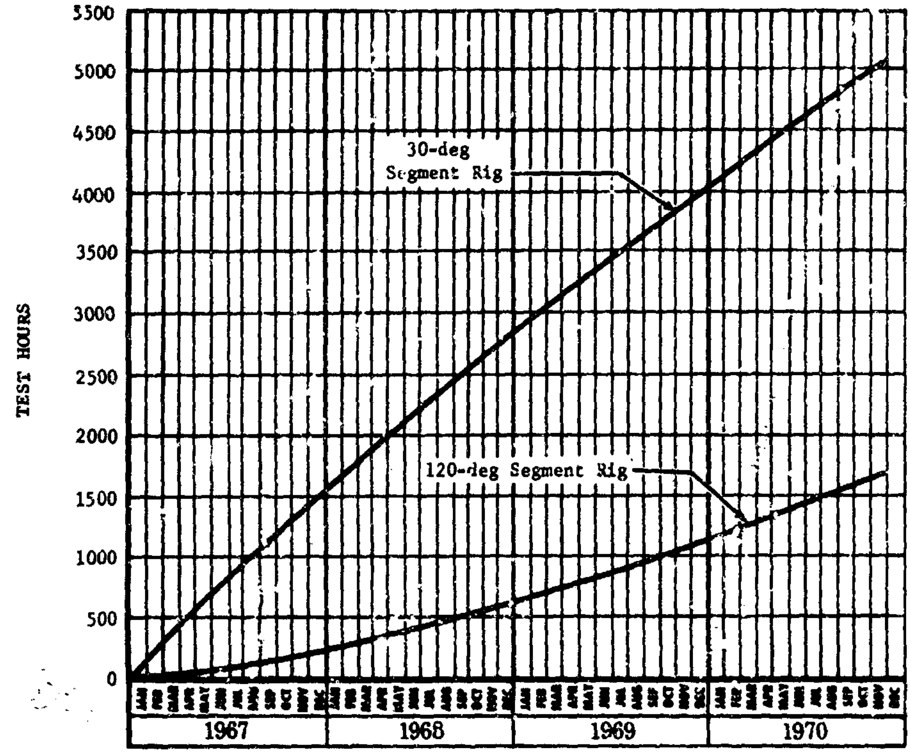

Figure 29. Segment Rig Testing

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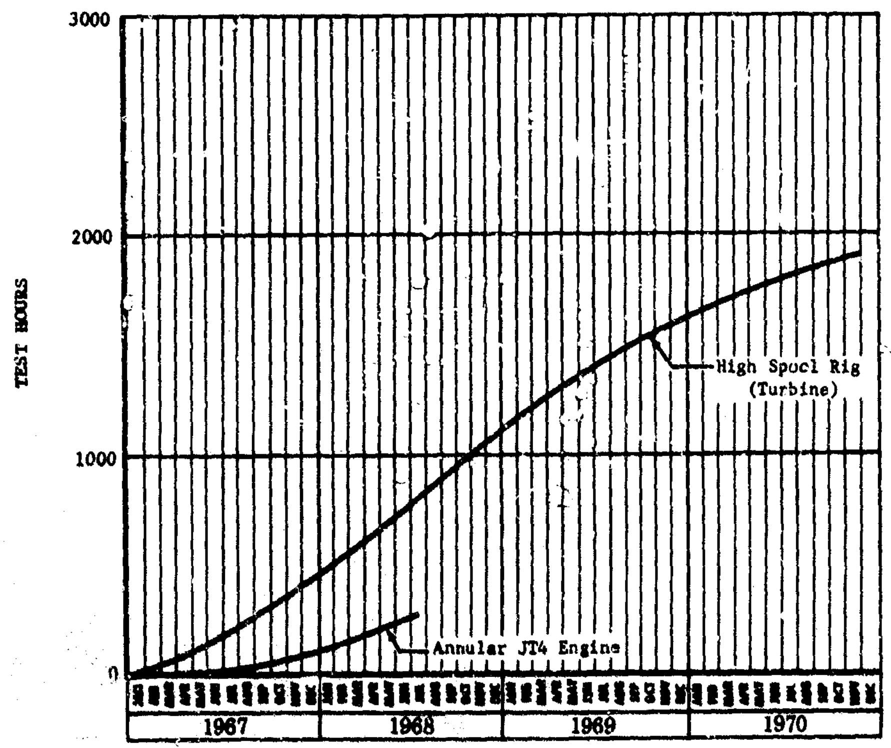

Figure 30. Annular Combustor Testing

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4. Turbine

a. Introduction

(1) Background

A rigorous and comprehensive turbine development program will be conducted, in conjunction with the JTF17 engine program to meet the reliability, durability, and performance goals of the engine. The development philosophy used in the turbine program is the direct result of experience gained in thousands of hours of development effort on earlier P&WA commercial and military engines, (i.e., JT3, J57, JT3D, JT4 (J75), J52, JT8, JT8D, TF30) and is an outgrowth of the air-cooled turbine technology derived in the Mach 3+ J58 program.

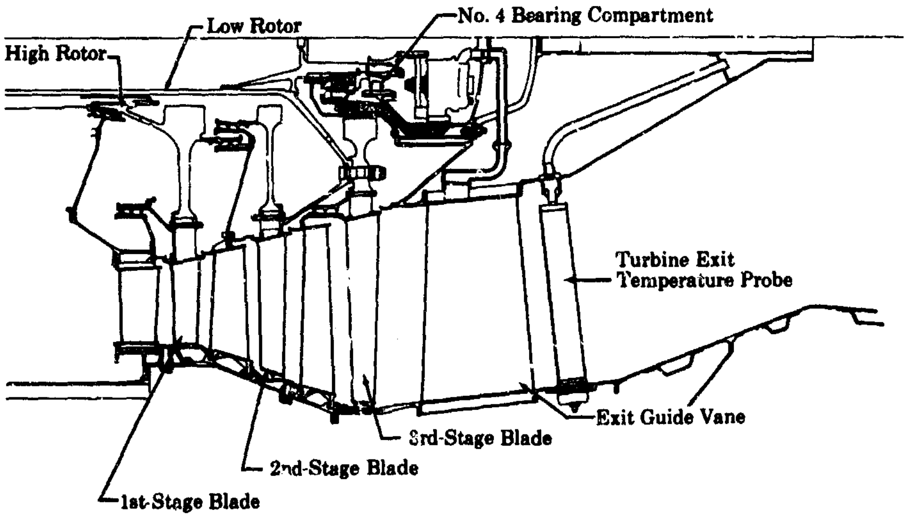


Figure 31. JTF17 Turbine FD 17015 EII

The JTF17 turbine, shown in figure 31, is a three-stage, axial flow, reaction type unit. The cooling system using compressor discharge air is designed for inherent reliability in that it is an integral part of the engine rotors and cases and is free from valving and other flow regulators which degrade reliability. Operation of the SST engine at turbine inlet temperatures approaching the melting point of most super alloys clearly indicates that the airfoil and cooling system must have designed-in reliability over a wide range of operating conditions. A comprehensive and vigorous turbine development program is vital to achieving the required reliability, durability and performance goals for the SST engine.

The turbine development plan for the JTF17 engine, presented in the following discussion, shows the overall program objectives, specific tests planned, description of rigs and test facilities, and includes graphic and tabular summaries of the planned development program.

(2) State-Of-The-Art

The design criteria for the JTF17 turbine, while demanding durability, reliability, and performance equal to current commercial aircraft turbine engines at gas temperature more than 500°F higher, is well within the air-cooled turbine state-of-the-art at Pratt & Whitney Aircraft. The aerodynamic and structural design criteria used in designing the turbine airfoils are in no way a radical departure from the experience factors gained in millions of hours of commercial jet engine service. Disk designs, with the aid of highly refined low cycle fatigue computer programs, have been tailored for 20 thousand cycle life at only a slight expense in engine weight. The J58 engine development has produced a stable of high temperature materials such that shaft designs are refined to the extent that material selection is made on the basis of economy rather than high temperature strength. A tabular comparison of aerodynamic and structural data for the JTF17 and other commercial and military engines is shown in tables 6 and 7. Turbine airfoil metal temperatures, although approximately the same as for modern commercial engines at takeoff, must remain at these levels for continuous supersonic cruise. Such turbine designs have been thoroughly evaluated in over 22,000 hours of J58 engine testing and are well within the capability of Pratt & Whitney Aircraft's material and coating systems.

The airfoil designs incorporate the latest refinements developed in Phase II-C. Significant improvements in performance and durability have been made by the following:

1. Controlled Vortex Aerodynamics - Provides 2% performance improvement over conventional free vortex designs, resulting in reduced engine weight.

2. High Efficiency Cooling Schemes - Reduces airfoil metal temperatures to levels experienced on current commercial engines at take-off while keeping the airfoil free from holes, slots, and other stress raisers that reduce reliability and encourage thermal fatigue failure. These designs avoid coolant system failures which result from clogging of small holes and slots, degradation from foreign object damage or malfunction of cooling supply valves which these designs do not require.

3. Metallurgical Improvements - Provide higher strength, greater ductility, resistance to intergranular corrosion-induced cracking, and superior quality which improve reliability at all engine operating conditions due to improved strength at elevated temperatures and superior resistance to thermal fatigue cracking.

Table 6. Turbine Aerodynamic Data

AERODYNAMIC TYPE	JTF17	J58	JT4	JT3	JT3D
	Controlled Vortex	Free Vortex	Free Vortex	Free Vortex	Free Vortex
Turbine Energy Extraction, Btu/lb					
High Pressure	116	145	76	71	68
Low Pressure	111		62	63	95
Turbine Pressure Ratio	5.6	3.1	4.3	4.3	6.8
Turbine Blade Tip Velocity, ft/sec					
1st Blade	1315	1230	1185	1070	1200
2nd Blade	983	1334	915	760	860
3rd Blade	1062		970	815	920
4th Blade					985

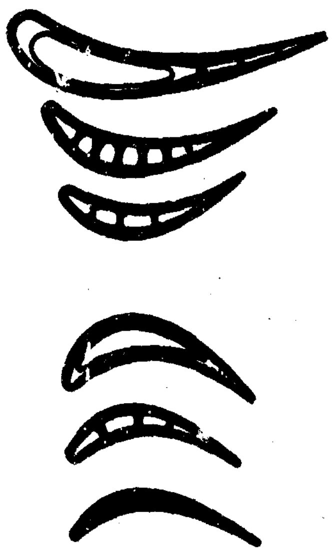
Table 7. Turbine Mechanical Data

	JTF17	J58	JT3	JT4	JT3D
Stage Exit Hub-Tip Ratio					
1st Stage	0.72	0.73	0.76	0.74	0.79
2nd Stage	0.58	0.63	0.71	0.67	0.72
3rd Stage	0.48		0.64	0.57	0.62
4th Stage					0.535
Turbine Blade Stresses, psi (Airfoil)					
1st Blade	16,100	13,700	14,400	15,900	14,800
2nd Blade	19,000	26,600	8,900	15,200	11,350
3rd Blade	26,400		12,600	20,200	14,450
4th Blade					22,600

(a) Phase II-C Component Status

Extensive Phase II-C turbine development efforts at Pratt & Whitney Aircraft have been effective in defining the thermodynamic and aerodynamic criteria for the JTF17 turbine design. Tests defining airfoil heat transfer characteristics, cooling effectiveness, long term endurance capabilities, thermal fatigue resistance, static and rotating aerodynamic characteristics, and oxidation/corrosion resistance were conducted to determine optimum thermodynamic, aerodynamic, and structural parameters for the airfoil designs. Results of these tests indicated that convection cooling offered the best choice of airfoil design from the standpoint of airfoil performance, cooling efficiency, durability, and quality control. The airfoil selection for the JTF17 turbine, together with cooling airflow

requirements and expected operating metal temperatures, is shown in figure 32. The first vane utilizes the leading edge impingement cooling concept with pedestal core and trailing edge exit. This configuration is a refinement of the J58 design and has consistently demonstrated the highest cooling effectiveness and the best chordwise thermal gradient for thermal fatigue control of any airfoil scheme tested.



VANE	AIRFOIL COOLING AIRFLOW, %	AVERAGE AIRFOIL METAL TEMP, °F
1st Stage	1.9	1700
2nd Stage	1.0	1617
3rd Stage	0.3	1543
BLADE		
1st Stage	2.0	1644
2nd Stage	0.5	1616
3rd Stage	0	1509

Figure 32. Turbine Cooling Data

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The second and third vanes employ spanwise flow convection cooling. The first blade utilizes the leading edge impingement cooling concept, with a cast in cooling tube and trailing edge cooling air exit. This design is essentially identical to the 1st vane and offers the same advantages. The second blade is convection cooled with spanwise flow and blade tip exit for shroud cooling. The third stage blade is solid and uncooled because of the lower temperature environment.

A thorough evaluation of convection cooling and film cooling was conducted to define heat transfer characteristics, aerodynamic loss coefficients, and low cycle fatigue capability. Representative film cooled airfoils tested during this study are shown in figure 33. The results of heat transfer tests of the convective and film cooled airfoils revealed that the cooling effectiveness ($\phi = \frac{T_{gas} - T_{metal}}{T_{gas} - T_{cooling\ air}}$) was approximately equal in both airfoil types up to cooling airflows of 2% gas generator flow as shown in figure 34. Below 2% cooling airflow, film cooling offers no thermodynamic advantages and tends to degrade reliability in the airfoil with its susceptibility to clogging.

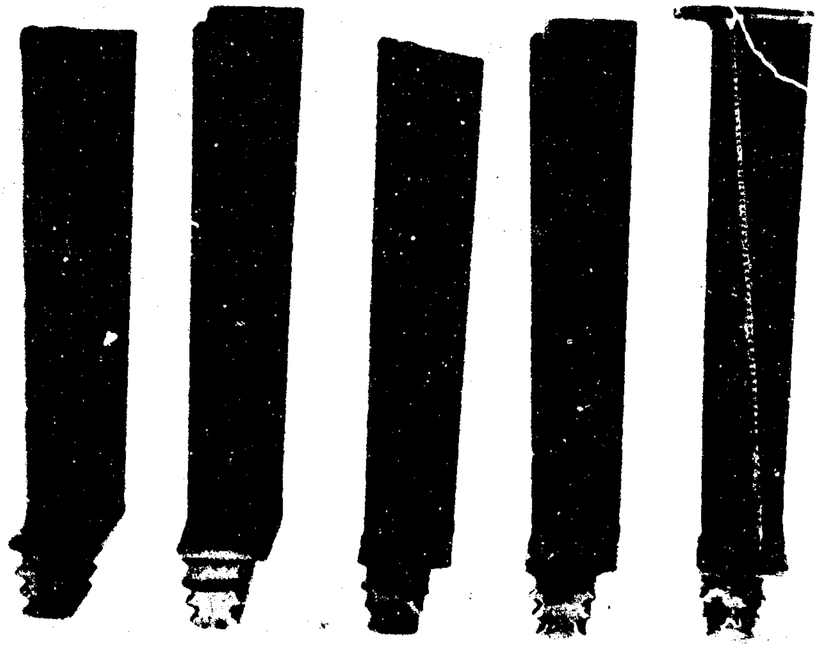

Figure 33. Representative Airfoils from Film Cooling Study (JT4 High Spool Rig) FE 60385 EII

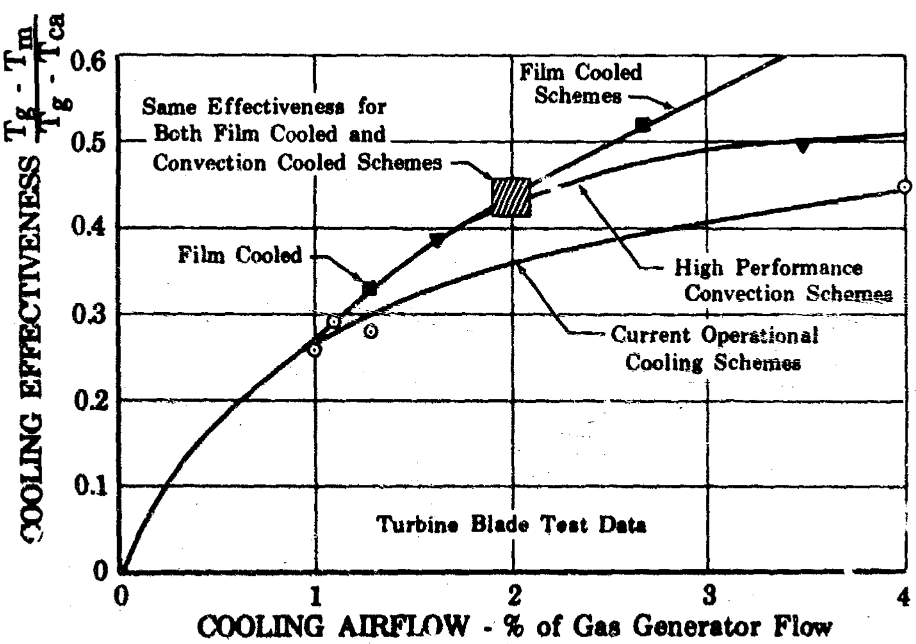

Figure 34. Cooling Effectiveness vs Cooling Airflow (Blade) FD 17640 EII

Aerodynamic tests were conducted both in static cascade rigs and rotating rigs on a series of convectively cooled and film cooled airfoils to determine optimum cooling air injection methods. High aerodynamic losses were encountered with virtually all film cooled configurations. The convective cooled airfoil with trailing edge cooling air discharge

yielded far superior performance and indicated that approximately 2% gas generator cooling airflow gave superior performance over any other combination tested, as shown in figure 35.

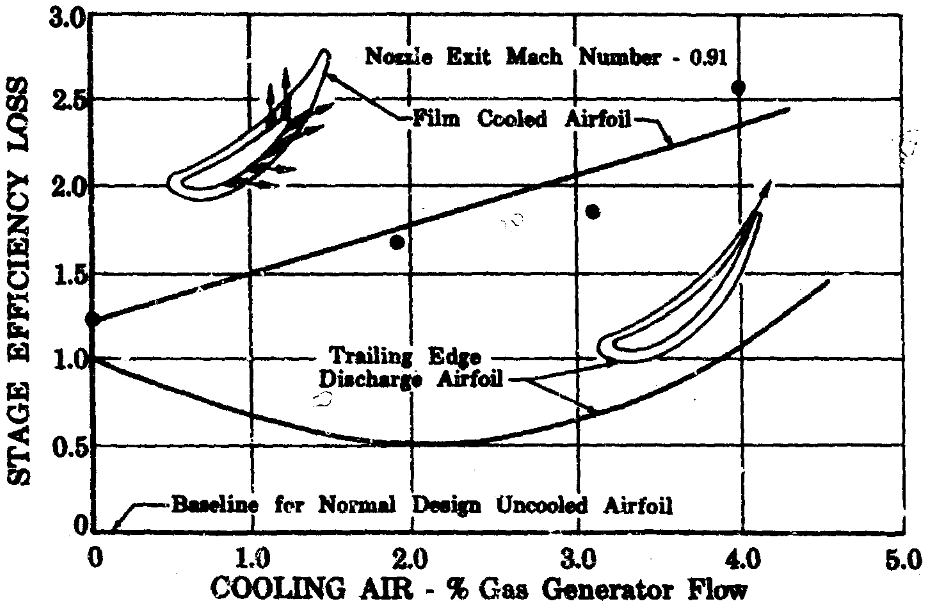

Figure 35. High Pressure Turbine Efficiency Loss vs Percent Cooling Air FD 17029 EII

Cyclic endurance tests conducted in the JT4 turbine development engine, shown schematically in figure 36, clearly indicated that slotted and drilled airfoils had very low resistance to thermal fatigue. The cyclic endurance consisted of engine accelerations and decelerations from idle to sea level take-off power (1100°F-2400°F turbine inlet temperature) in one minute intervals simulating expected JTF17 engine operating conditions. All representative film cooled blades failed in thermal fatigue in 100 cycles or less. Comparable convectively cooled airfoils cycled under the same conditions showed no thermal fatigue cracking when tested for 3000 cycles, which is equivalent to approximately 5000 hours of commercial service operation.

High temperature endurance tests of 200 hours duration were conducted in the JT4 turbine development engine up to 2500°F turbine inlet temperature to test the integrity of candidate materials and coatings for the JTF17 design, as shown in table 8. Blade materials evaluated were PWA 663 (B-1900), PWA 658 (IN-100), and PWA 664 (MAR-M-200). Cooling air temperature delivered to the blades simulated JTF17 engine sea level take-off, and cooling air quantity was set to maintain airfoil metal temperature in the 1650°F to 1700°F range. Excellent durability was demonstrated by the PWA 658 and PWA 664 airfoils using PWA 47 coating.

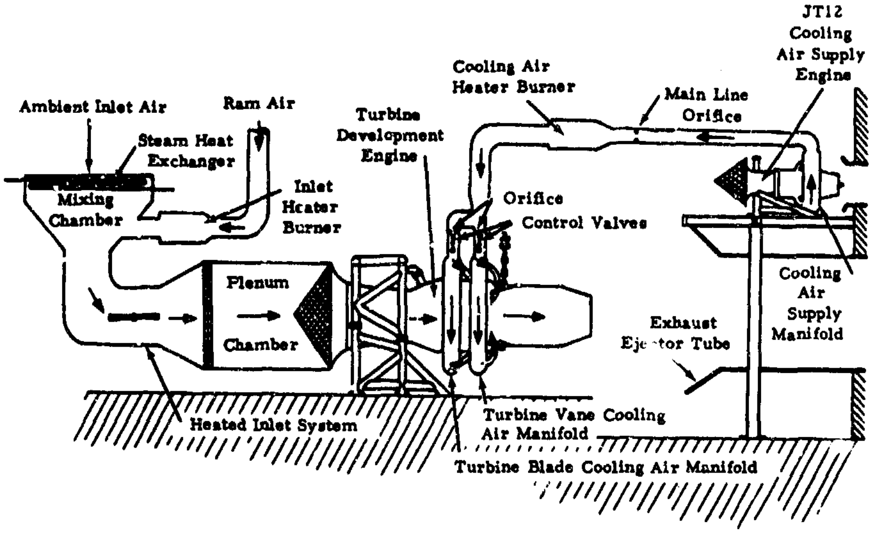

Figure 36. Turbine Development Engine Installation X-20 Stand FD 13082 EII

A major advancement in the state-of-the-art of airfoil cooling was made with the Thermal Skin convection cooling concept. Refinements of this form of airfoil cooling resulted in the definition of the 4-wall impingement cooled leading edge, first stage turbine blades shown in figure 37. This highly efficient configuration produces a cooling effectiveness of 0.480 at cooling airflows of 2% of gas generator flow. The impingement cooled leading edge concept offers an excellent method of controlling the chordwise temperature gradient which profoundly influences thermal fatigue life. The absence of slots, holes, and other interruptions in the stressed wall of the airfoil permits meeting the life and durability goals of the JTF17 engine for commercial service.

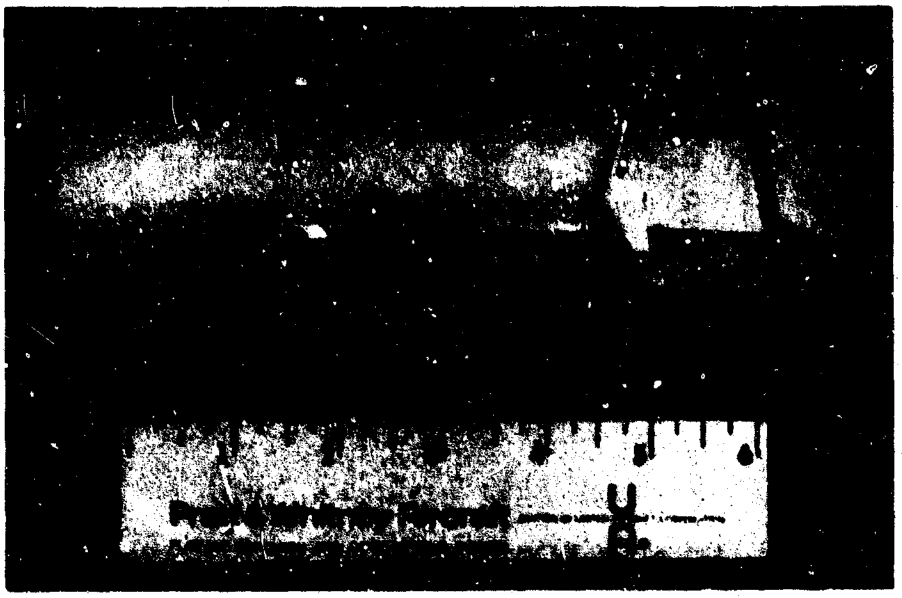

Figure 37. Four-Wall Turbine Blade FE 60779 EII

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Heat transfer testing of the second stage blade and vane airfoils has been completed and has verified the suitability of these designs for the JTF17. Metal temperature plots showing chordwise thermal gradients for these airfoils are shown in figures 38 and 39.

Table 8. SST Turbine Engine Test Summary

Full Scale Engine Tests

At JTF17 Cruise T.I.T. (2200°F)		
	Vanes	230 hr
	Blades	105 hr
At JTF17 Takeoff T.I.T. (2330°F)		
	Vanes	200 hr
	Blades	200 hr
At 200°F Above JTF17 Takeoff T.I.T. (2500°F)		
	Vanes	200 hr
	Blades	200 hr

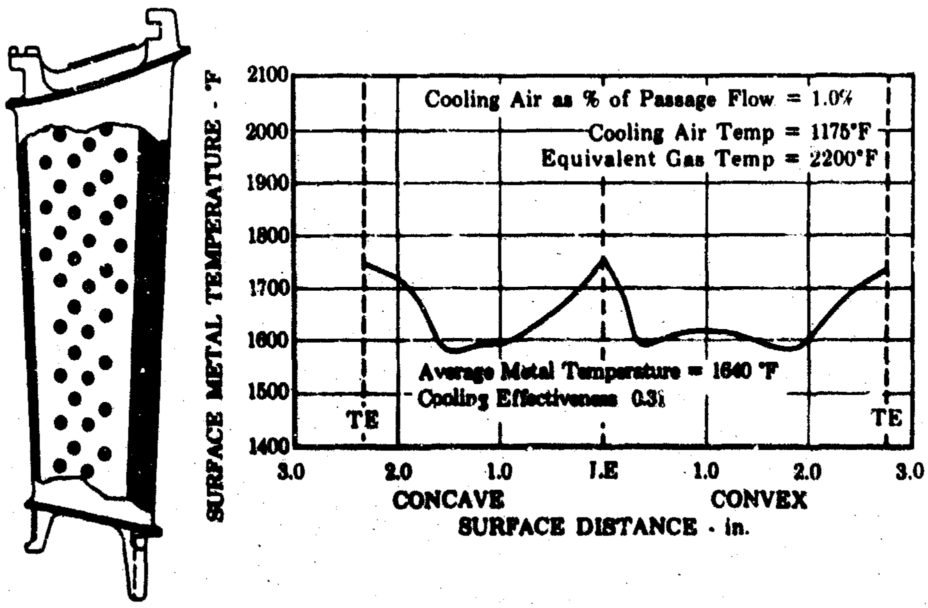

Figure 38. 2nd-Stage Vane Test Data

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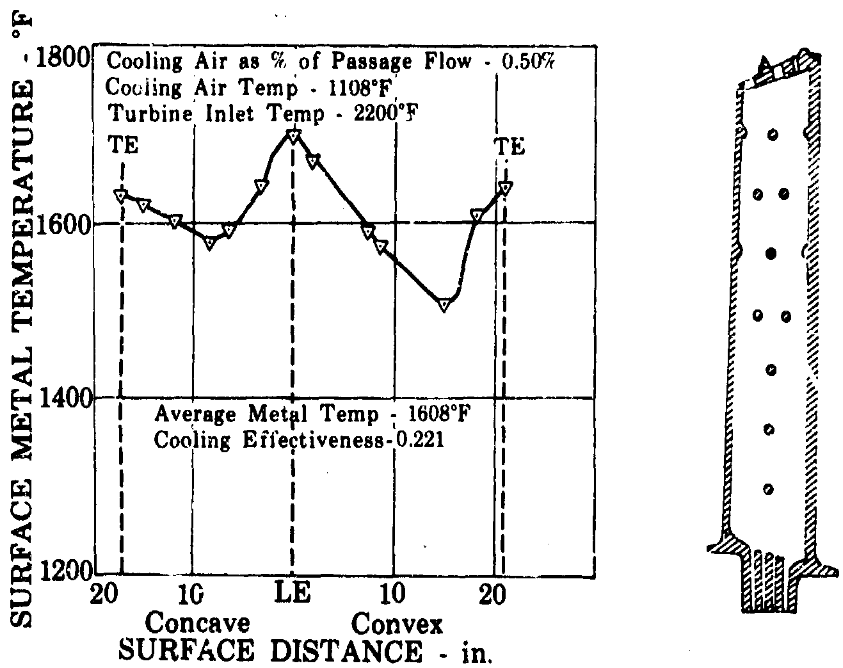

Figure 39. JTF17 2nd-Stage Blade and Test Data FD 16816 EII

Metallurgical efforts conducted during Phase II-C have led to the development of improved high temperature disk and sheet alloys. Laboratory efforts on these materials are continuing. Development efforts on the directionally solidified turbine blade and vane materials (i.e., PWA 664 and PWA 1401) has led to the procurement of full-scale engine hardware for both commercial and military engines. Evaluations are currently in progress. Long term creep and stress rupture testing of candidate materials begun in Phase II-C have reached the 2000 to 4000-hour range. The results of these tests are being used to update design materials criteria in the range from 1000 to 10,000 hours. Complete details are presented in Volume III, Report F, Section II.

Coating development efforts during Phase II-C have been extensive. Long term erosion tests with salt and sulfur contaminants have been carried out to further define the sulfidation phenomenon and to assist in material selection for the JTF17 design. Research efforts in coating development have led to the definition of a new coating system (PWA 59) compatible with PWA 658, which appears superior to PWA 47. Additional research efforts have led to the definition of methods of bonding high oxidation/sulfidation resistant coatings to conventional turbine super alloys. Accelerated laboratory tests at 1800°F metal temperature indicate that one coating (Fe CrAl) coextruded over IN-100 is impervious to sulfidation and oxidation attack up to 2300 hours of testing. A weight loss vs time plot of candidate coatings is shown in figure 40.

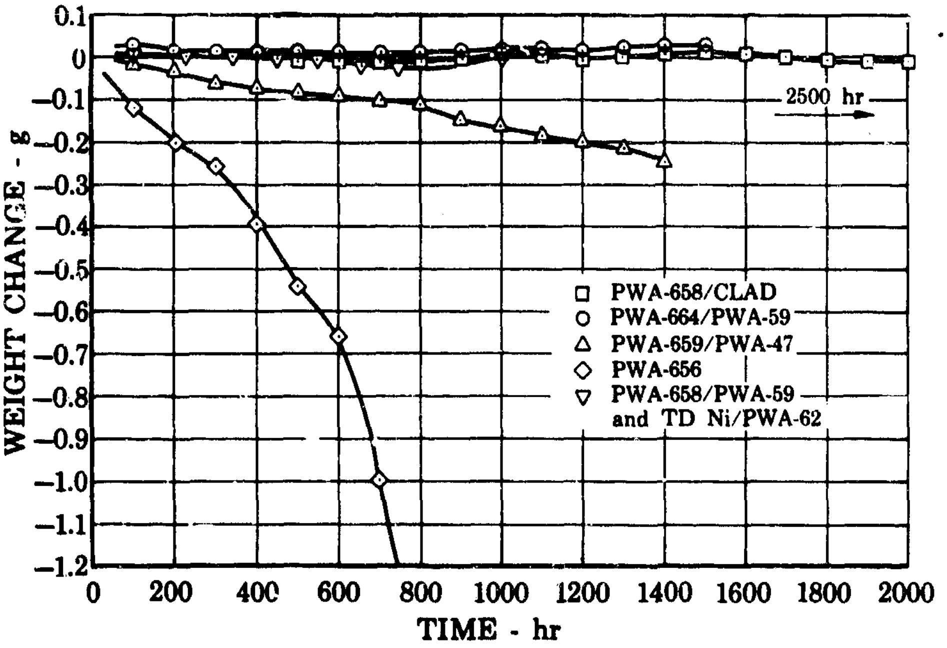

Figure 40. JTF17 Sulfidation Tests at 1800°F on FMDL Erosion Test Facility — FD 17038 EII

b. Phase III Component Development Test Program Objectives

A rigorous and comprehensive turbine development program will be accomplished during the proposed Phase III program. Major emphasis will be directed toward the development of low cycle fatigue resistance, oxidation/corrosion resistance, sulfidation resistance, and development and demonstration of performance and reliability goals of the turbine design. The following general test categories will be pursued:

1. Design Verification - Tests will be conducted on airfoils and disks to verify the design criteria used in formulating the JTF17 configuration. These tests will include heat transfer analysis, erosion/corrosion evaluations, low cycle fatigue resistance, and structural evaluations.

2. Configuration Refinement - Tests will be conducted on prototype airfoils to refine cooling schemes and achieve optimum definition of chordwise and spanwise thermal gradients for maximum resistance of erosion and low cycle fatigue.

3. Endurance Tests - Long term endurance tests will be conducted on airfoils to demonstrate adequate reliability margin of the airfoil in meeting the initial TBO target of 600 hours with growth capability to 10,000 hours.

4. Aerodynamic Refinement - Tests will be conducted on airfoils to refine aerodynamic parameters to provide improved performance of the turbine with no increase in weight.

5. Materials/Coatings - Continued laboratory development work will be expended to further define the high performance

coating systems under investigation for ultimate use in the JTF17 engine desi to extend engine parts life beyond the initial TBO goals

6. Airfoil Fabrication Techniques - Testing will be conducted on airfoils featuring maintainability provisions. Emphasis will be placed on the alternative versions of the four-wall blade which feature a removable, self-supporting impingement cooling tube. This arrangement allows significantly reduced costs and simplified manufacturing procedures.

7. Improved Cooling Schemes - Testing will be conducted on new airfoil cooling innovations which are considered alternatives to the prototype configuration. Among these are:

   a. Airfoils which offer ultimate cooling efficiency by virtue of increased length-to-diameter ratio cooling air passages such as the laminated wafer vane, shown in figure 41.

   b. Variable cooling schemes which employ thermostatically controlled cooling air throttling to refine cooling air requirements to the vanes to most efficiently use the air at the locations required. A schematic of one promising system is shown in figure 42.

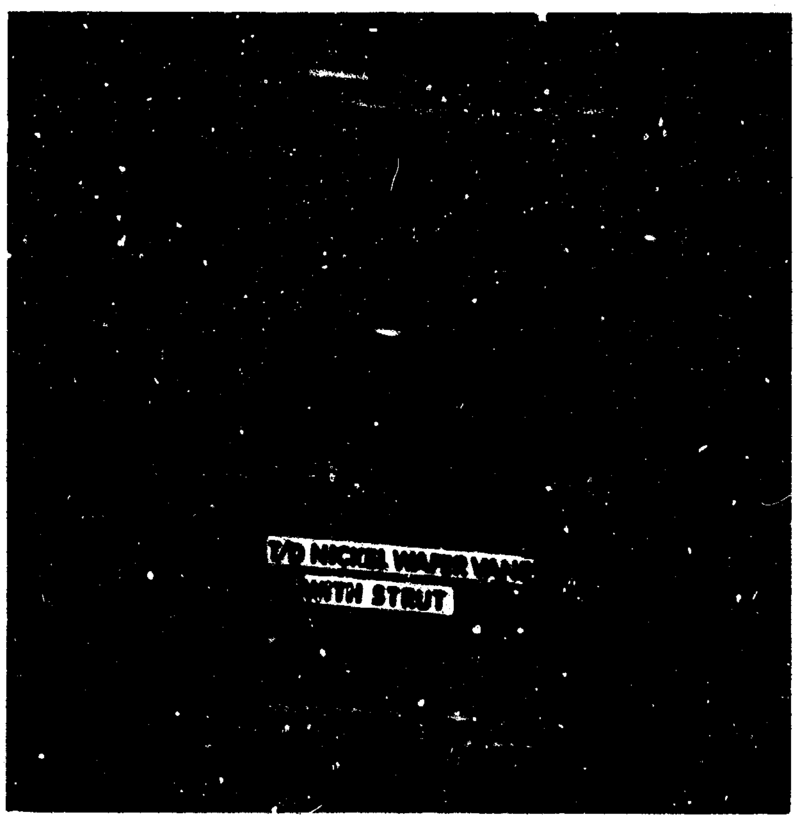

Figure 41. T/D Nickel Wafer Vane With Strut

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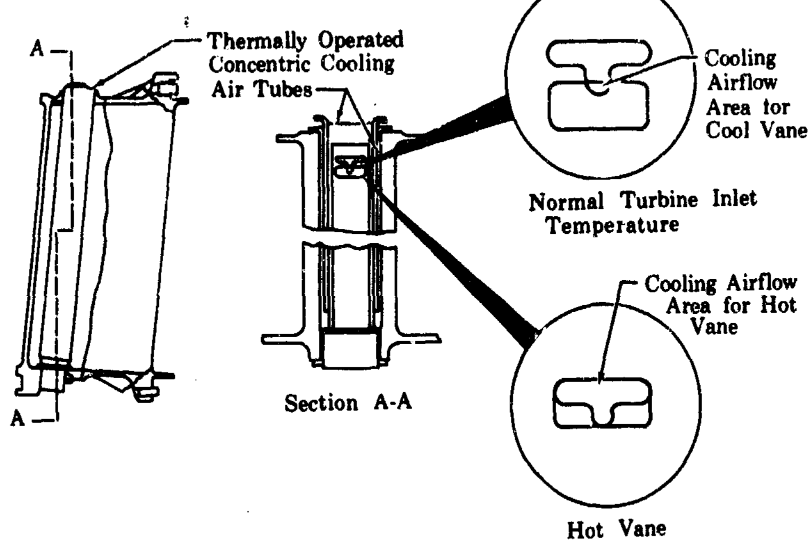

Figure 42. 1st-Stage Vane Variable Cooling FD 17020 EII

8. Engine Tests - Full-scale engine tests will be conducted on instrumented turbines to ensure accurate correlation of rig data. Performance evaluations will be made of the cooling air circuit to minimize losses resulting from leakage.

c. Description of Component Test Rigs

(1) JTF17 Turbine Development Engine (High Spool Rig)

The JTF17 high spool rig, similar in concept to the JT4 high spool rig, will be procured early in the Phase III development program. The rig, shown schematically in figure 43, will consist of a JTF17 engine with the duct heater assembly, fan assembly, and low turbine assembly removed. An inlet adapter section will be provided with a heater and a calibrated orifice for engine airflow measurement. This rig is self contained and can be run on a standard sea level test stand. The high spool rig configuration allows extended operation at elevated temperatures with a minimum of operational problems, and simplifies the replacement of high pressure turbine test parts. The rig will use full-scale JTF17A-21 engine parts, thus simplifying procurement problems and facilitating testing of alternative engine configurations. The turbine inlet temperature capability of the High Spool Rig and rate of acceleration and deceleration will closely approximate actual full engine operation.

A simplified control system will be used which will schedule automatic acceleration and deceleration cycling for realistic evaluations of low cycle fatigue. The single spool concept offers ease in procuring data on the high pressure rotating turbine because it eliminates the need for a telemetry system to transmit data across the concentric shaft configuration of the complete engine.

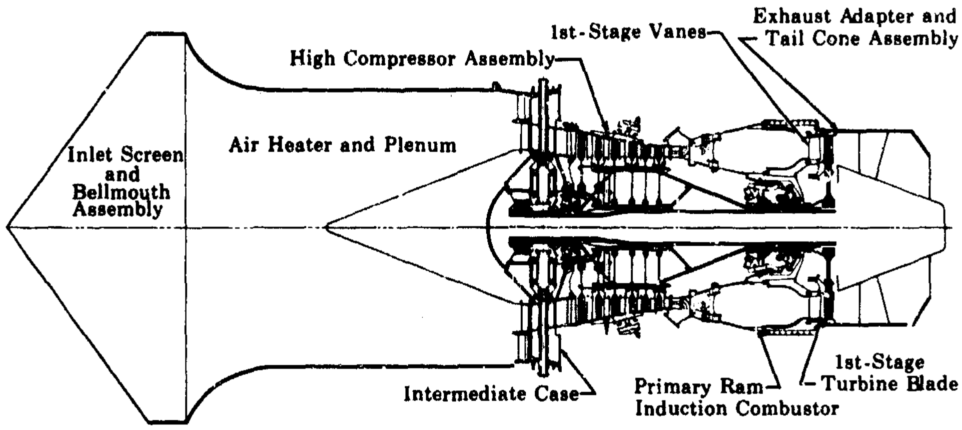

Figure 43. JTF17 Turbine Development Engine - High Spool Rig FD 16504 EII

(2) Heat Transfer Rigs

Turbine airfoil thermodynamic testing will be accomplished in modified versions of existing annular segmented cascade rigs shown in figures 44 and 45. These rigs are capable of testing full-scale JTF17A-21 airfoils under actual engine environments, with the exception of the effects of rotation. The rig consists of an inlet plenum equipped with air measurement instrumentation, a burner section utilizing two can-type burners in tandem, a transition section, a cascade test section for either blades or vanes, and an exhaust section. The transition section contains a removable insert which provides the proper air incidence angle on the blade or vane test section. The rig walls are water cooled to facilitate gas temperature operation up to 2500^{o}F. Airfoil cooling air is supplied from a separate compressor unit and can be heated to 1500^{o}F to simulate the effects of high Mach number.

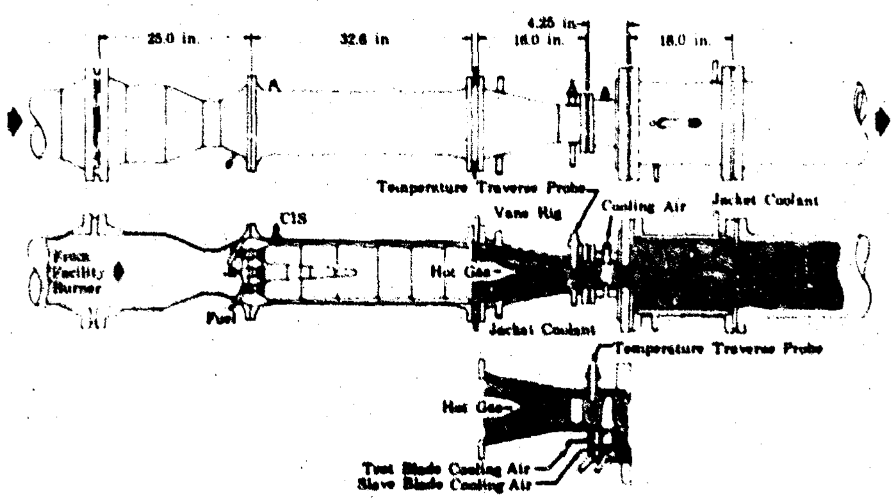

Figure 44. Annular Segment Heat Transfer Rig FD 16505 EII

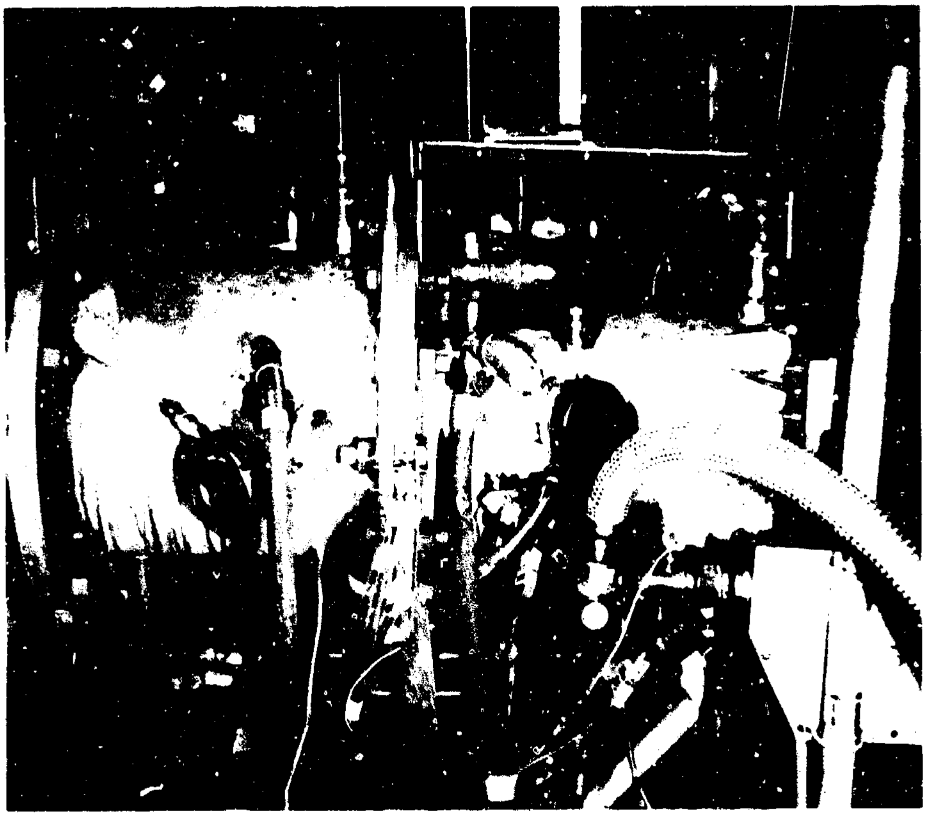

Figure 45. Annular Segmented Cascade Rig FE 54709
EII

Automatic rig pressure and temperature controls and automatic data recording systems are incorporated in the facility to provide fast, accurate, and reliable data from the heat transfer tests.

The gas stream total pressure and temperature profiles are determined by a traversing probe located immediately upstream of the airfoil cascade. An uncooled shield is used immediately downstream of the test section to regulate radiation effects.

(3) Thermal Fatigue Rigs

(a) Open Flame Thermal Fatigue & Erosion Rigs

These existing rigs are used primarily in screening tests to determine coating durability and inherent resistance of blade and vane materials to thermal fatigue. The thermal shock rigs shown in figure 46 consist of an open flame torch-type burner, specimen holder, and a solenoid operated air valve. The efflux from the burner impinges on the test specimen to produce the "heat on" cycle. The shop air solenoid is actuated to deflect the hot gases away from the test specimen, producing the "heat off" cycle. The erosion rigs, shown in figure 47, consist of the open flame torch-type burner and a 1750 rpm motor fitted with a specimen holder. The specimens are run at 1800°F metal temperature with careful weight measurements made

at 50-hour intervals. The burner is fired with reference fuels representative of the low quality range of the fuel specified for the engine, and the gas velocities are set to approximate turbine inlet Mach numbers. The rigs are equipped for salt contaminant injection for sulfidation evaluations of the materials and coating systems.

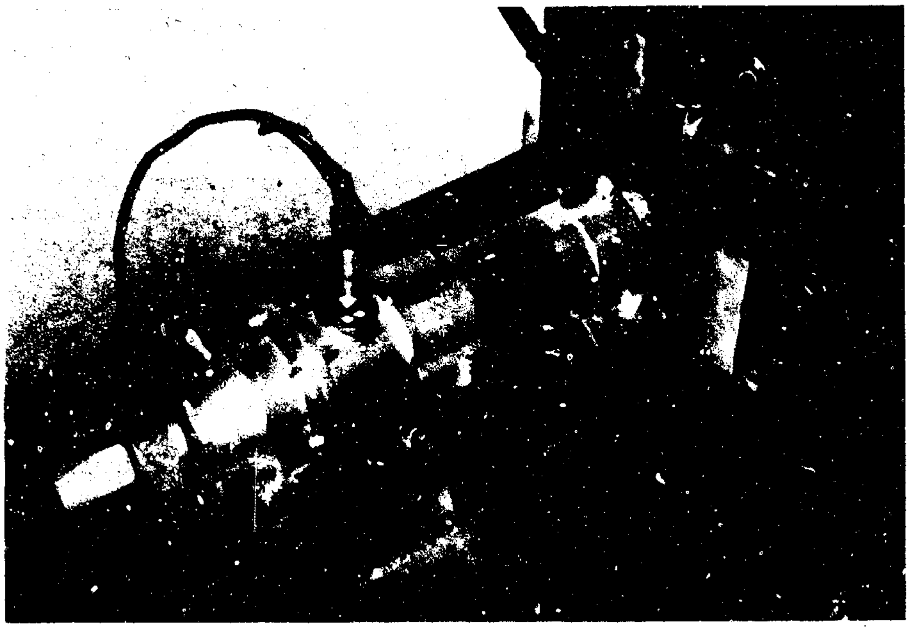

Figure 46. Thermal Shock Rigs FE 55717 EII

Figure 47. Erosion Rigs FE 61466 EII

(b) Cascade Thermal Fatigue Rig

The cascade thermal fatigue rig, which became operational during Phase II-C, will be used to continue evaluations of thermal fatigue resistance of blade and vane airfoils. The rig, shown in figure 48, is composed of five basic sections: (1) inlet plenum, (2) burner section, (3) transition section, (4) blade or vane section, and (5) exit section.

Thermal cycling is accomplished with an electrical timing system that controls the temperature, pressure and flow of the primary and coolant gas streams. The timing system allows adjustment over a wide range of cycle times to allow for simulated engine transient testing as well as accelerated cyclic testing. Special design features of the rig are:

1. Water cooled design capable of gas temperatures to 4000°F
2. Structural design for gas stream pressure level of 200 psia
3. Replaceable heat shield to reduce thermal radiation losses and increase test unit life
4. Offset exit flow path to minimize vane or blade trailing edge thermal radiation loss
5. Provision for removal and replacement of these vanes or blades in the test stand
6. Control of the incidence air angle to the test blades with various inlet turning vanes to simulate conditions encountered with rotating blades
7. Provisions for supplying heated cooling air to test blades or vanes
8. Provisions for minimizing radiant heat losses by cooling slave vanes so that their metal temperature can be maintained close to that of the test blade or vane.

(4) Aerodynamic Rigs

(a) Annular Segment Rig

The aerodynamic annular segment rig is depicted in the schematic of figure 49. This unit is an adaptation of a J58 size heat transfer rig. Bleed air is supplied to the rig from the test stand slave engine. Airflow is measured with an ASME standard orifice. A screen is installed at the burner case inlet to provide a uniform velocity profile. Fixed inlet total pressure and total temperature probes are installed upstream of the annular transition duct. Mainstream flow is directed through a nine-passage segmented annular cascade. Total and static pressure are simultaneously measured at the airfoil exit with remotely controlled transonic traverse probe which is capable of both circumferential and radial movement. Axial position of the probe can be adjusted within 0.010 inch and angular position about the radial axis can be adjusted within 0.5 degree. The photograph of figure 50 shows a view of the cascade exit and the installation of the conical traverse probe. Cooling air is supplied to the test parts for air ejection evaluation. Flow is measured with an ASME standard orifice, and inlet total pressure and temperature are measured in a plenum chamber.

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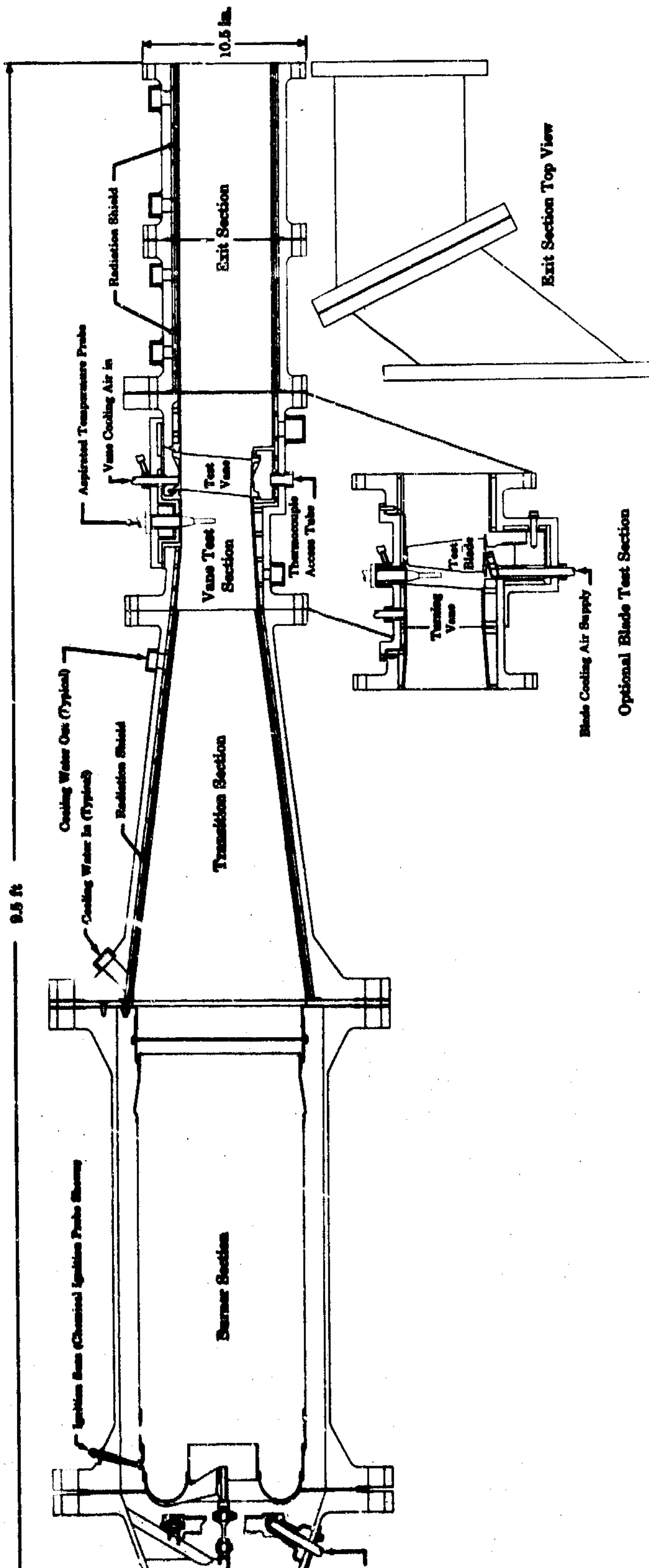

Figure 48. High-Temperature Turbine Cascade Thermal Fatigue Test Unit

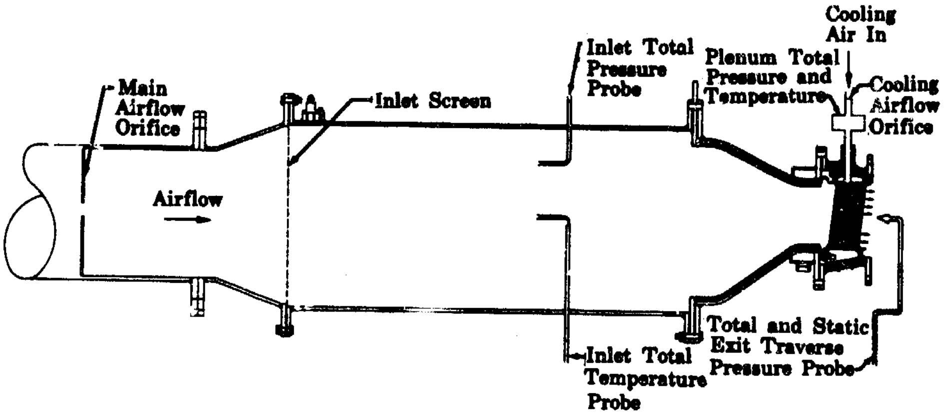

Figure 49. Aerodynamic Performance ıscade Rig Schematic — FD 17014 EII

Figure 50. Aerodynamic Test Rig, View of Cascade Exit — FD 16506 EII

All instrumentation is recorded with digital microsadic recording equipment, and visual readout stripchart recorders are used for real-time monitoring. The microsadic data tape is processed through a computer, and aerodynamic loss coefficients are printed out along with computed airflow rates and Mach numbers.

The operating limits of the rig are set by the capabilities of the test stand air supply and the rig flow area. Primary and cooling air are used as received from the slave engine compressor bleed ports, and maximum operating conditions are as follows:

1. Inlet pressure (total) 40 psia
2. Inlet temperature (stagnation) 550°F
3. Flow rate (9-passage cascade) 21 lb/sec

A new vane test section that will accept JTF17-size vanes will be procured with a suitable transition duct and inlet plenum chamber. This will allow realistic aerodynamic performance evaluation of the actual engine first vane configurations. The segmented annular configuration of this rig will allow performance evaluation in the spanwise direction, which is important with the controlled vortex designs because of the spanwise geometry variations. Although this rig is limited to non-rotating normal incidence turbine components, such as the 1st-stage vane, its value is evident by the following advantages:

1. Segmented Annular Shape - The 1/8 engine size segment produces realistic pressure gradients in both the chordwise and spanwise directions. Vane discharge angles can be accurately determined for the complete span.

2. Engine Parts - The test section will accept actual engine hardware, which results in better flow field simulation and economy.

The aerodynamic annular segment rig will be used in the refinement of airfoil aerodynamic parameters to provide performance growth of the turbine.

(b) Plane Aerodynamic Cascade Rig

The plane aerodynamic cascade rig, shown schematically in figure 51, will permit aerodynamic evaluation of proposed designs and configuration changes without the necessity of fabricating a complete set of components for rotating rig testing. Considerable economy and design versatility will be achieved because a small number of parts can be fabricated inexpensively and rapidly. The components can be made from easily machined aluminum, eliminating complicated fabrication problems. This rig will be capable of evaluating basic airfoil profile performance of both blade and vane configurations with cooling air ejection. A conventional cascade is proposed. Although spanwise pressure gradients and flow fields cannot be simulated as for the segmented annular rig, the rig will have variable incidence angle capabilities and mean line design blade profile performance that can be evaluated. In addition, designs can be screened for camber and solidity effects prior to rotating rig test evaluation.

The proposed rig will be an 8- to 10-component plane cascade. Mid-span blade and vane airfoil shapes and spacing will be simulated and carried from root to tip without twist or divergence. Span length will be similar to that in the engine. Variable incidence angles will be provided by the selection of the proper inlet transition duct which attaches to a plenum chamber. A linear traverse system will be used for pressure and temperature measurement.

Operating limits on this rig will be essentially the same as those for the segmented cascade rig. This will allow testing over the normal turbine operating Mach number range and beyond, up to a Mach number of approximately 1.2.

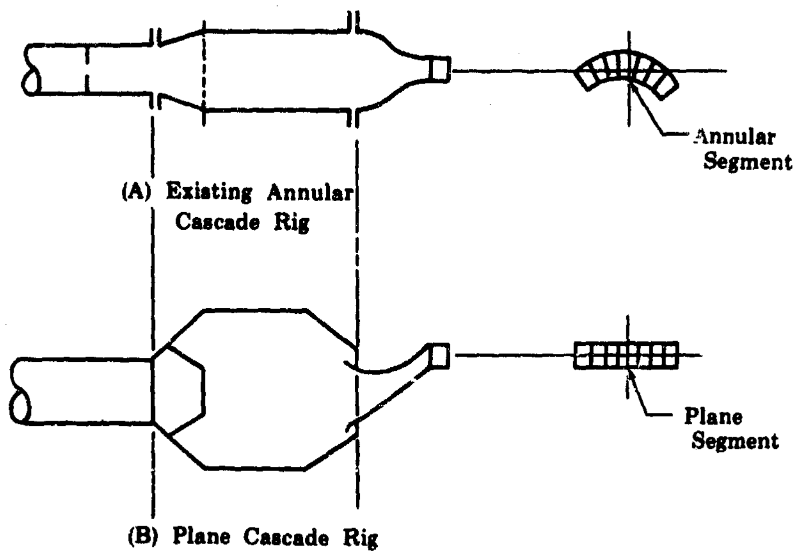

Figure 51. Static Aerodynamic Performance Cascade Rigs FD 16507 EII

(5) Component Test Facilities

Test stands and facilities required to support the turbine development program are available within FRDC. Complete details of the facilities required to support the JTF17 engine and component development may be seen in Volume V, Report B, of this proposal.

The following test stands and facilities will be used in the turbine development program:

(a) JTF17 High Spool Rig

The FRDC sea level test stands will be used for testing of the high spool rig. An inlet air heater will be part of the rig to simulate fan discharge temperatures (approximately 250°F) at the inlet to the high spool rig. Blade and vane cooling air will be supplied from slave engines currently operating in the test area. Data recording systems and instrumentation channels currently available in the test stands are adequate for the high spool rig testing.

(b) Heat Transfer Rigs

Existing FRDC test stands (C-1, B-2, and A-11) which are currently being used in Phase II-C will be used for heat transfer testing during Phase III. The C-1 stand, shown in figure 52, is an integral part of the high Mach number laboratory and is equipped with ram and exhaust

capability as well as hea..d air supply. The A-11 and B-2 stands are driven by air supplied from slave JT3 and JT4 engines and thus operate independently of other test stands. All of these stands are equipped with automatic data recording systems, temperature and pressure control systems, and remotely operated traversing systems.

Figure 52. C-1 Test Stand FC 12705 EII

(c) Materials and Coating Development Rigs

Existing facilities in the Materials Development Laboratory will be used in continuing studies of material and coating development. A general view of the rig room, with erosion rigs in operation, is shown in figure 53.

(d) Low Cycle Fatigue Rigs

The annular segment thermal fatigue rig will be run in A-11 stand currently being used in Phase II-C development activities. A brief description of the test stand has been given above in the Heat Transfer Rig Section.

(e) Aerodynamic Rigs

The annular segment cascade rig and the plane cascade rig will be run in B-2 stand, shown in figure 54, which is currently being used in Phase II-C development activities. The stand is complete in its current configuration and will accommodate both rigs simultaneously. Operating limits of the stand are as follows:

Inlet Pressure	40 psia
Inlet Temperature	550°F
Airflow Rate	21 lb/sec

Figure 53. Erosion Rigs in Operation FC 8523 EII

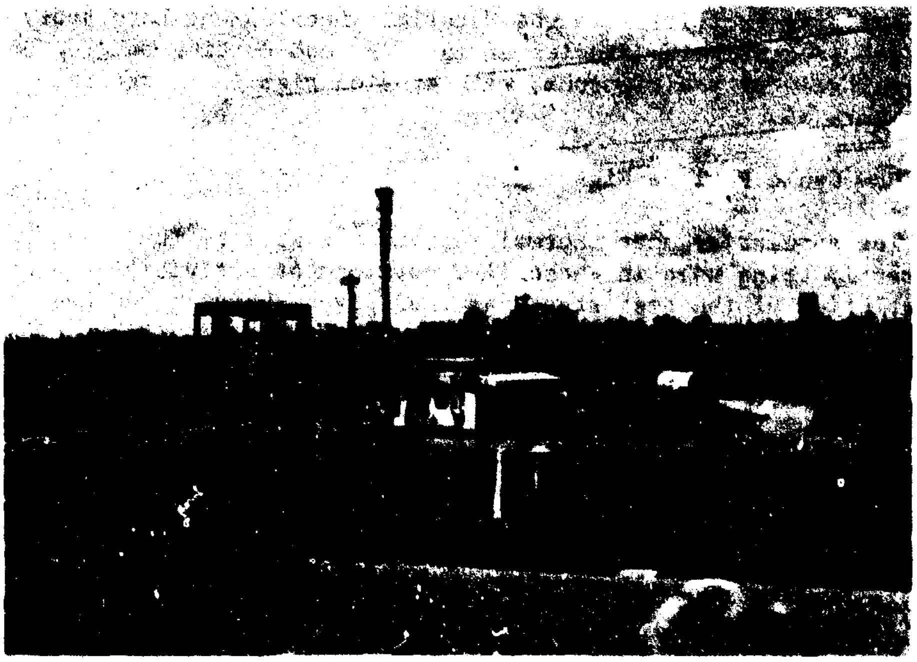

Figure 54. B-2 Stand FC 9918 EII

(6) Component Rig Instrumentation

Considerable development effort has been exerted at Pratt & Whitney Aircraft on instrumentation techniques for engine and component development during Phase II-C and during previous high Mach number engine programs. Reliable techniques have been developed for instrumenting engine parts with high temperature strain gages and thermocouples, as well as a variety of vibratory sensors and potentiometers.

Specialized instrumentation, such as the application of 0.010-inch OD ceramo tubing with 0.003-inch thermocouple wire to turbine blades and vanes, is being used daily in heat transfer testing. To avoid disturbing the boundary layer around the airfoil by the projection of the wire into the gas path, channels are electro discharge machined (EDM) into the airfoil skin to act as routing paths for the wire. The wire is laid into the slot, peened into place, and covered with special cement to form a test specimen similar to the blade shown in figure 55.

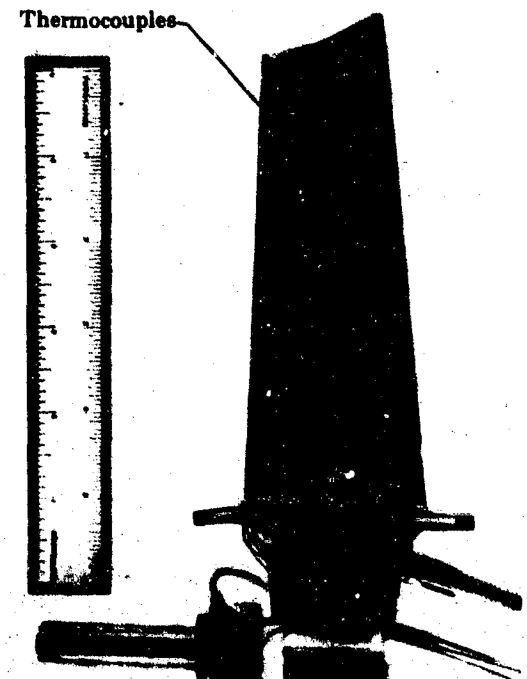

Figure 55. Instrumented Turbine Blade for Heat Transfer Rig Testing FD 16615 EII

A telemetry system for transmitting data from the twin-spool, concentric-shaft engine has been built and is being used successfully in engine tests. Additional new methods for data acquisition are being evaluated. The most promising of these is the Kryptonating process currently being developed for airfoil temperature measurement. The test part is diffused under pressure and temperature with Krypton 85 gas and tested in an engine or rig. Evaluations are made with special radioactivity measurement devices to determine the maximum surface

temperature experience of the part after its removal from the test vehicle. A kryptonate, when heated, outgasses at an exponentially decreasing rate that approaches zero. The residual gas concentration in the surface of the metal is determined by the maximum exposure temperature; thus, the specimen has a built-in memory of the maximum temperature imposed. By taking the specimen, measuring the radioactivity as a function of temperature, and finding the point at which outgassing begins (i.e., the kryptonate breaks), it is possible to determine the maximum temperature experienced by the part in the test. This system is useful in completely mapping the surface temperature experienced by the airfoil for thermal fatigue evaluations.

d. Component Test Program

The Phase III turbine development program for the JTF17 engine consists of the following tests:

1. Static Airfoil Heat Transfer
2. Static Airfoil Thermal Fatigue
3. Disk Spin Test
4. Disk LCF Test
5. Transient Airfoil Heat Transfer
6. Airfoil Cyclic endurance
7. Cooling Circuit Performance
8. Structural (Blade & Disk)
9. Airfoil Endurance
10. Aerodynamics
11. Materials & Coating Development

The test schedule, rig involved, number of builds, and accumulation of test hours is shown in figures 56 through 60. A brief description of the included programs is as follows:

(1) Static Airfoil Heat Transfer Tests

Heat transfer testing will be conducted on the 1st- and 2nd-stage turbine airfoils in the segmented annular heat transfer rigs to confirm design criteria and establish any necessary cooling scheme refinement. These tests will be conducted on the airfoils individually and will start with the 1st-stage blade. The airfoils will be instrumented with approximately 30 thermocouples having a heavy concentration at the mid-span of the airfoil where stresses and temperature become critical. The test airfoil is air-flowed prior to installation into the test rig to determine flow parameter and to assure that the cooling system is clean. The thermocouples are tested, checked for location, and tagged for identification.

The test consists of approximately ten data points, five each at sea level takeoff and cruise. Rig gas temperatures are set at 2300°F for sea level takeoff and 2200°F for cruise, while the cooling air is set at 700°F and 1100°F for sea level takeoff and cruise, respectively. The pressure drop across the cascade is set to simulate the approximate Mach number in the turbine and is held constant by an automatic pressure regulating device. Data points to either side of the design point are set by varying cooling airflow.

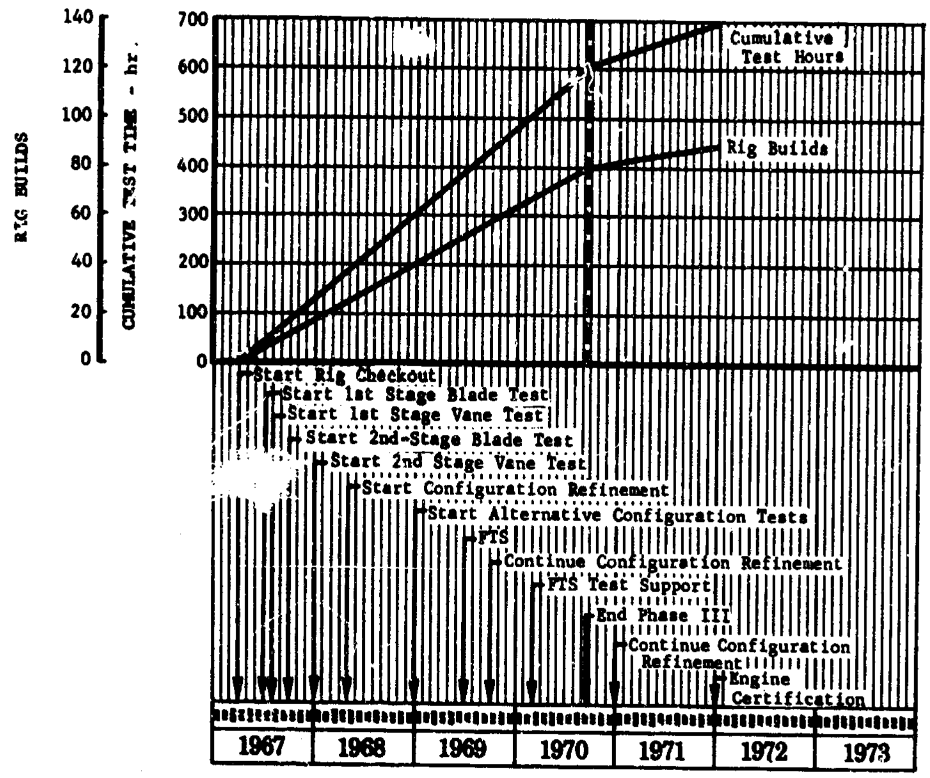

Figure 56. Heat Transfer Rig Schedule FD 16509 EII

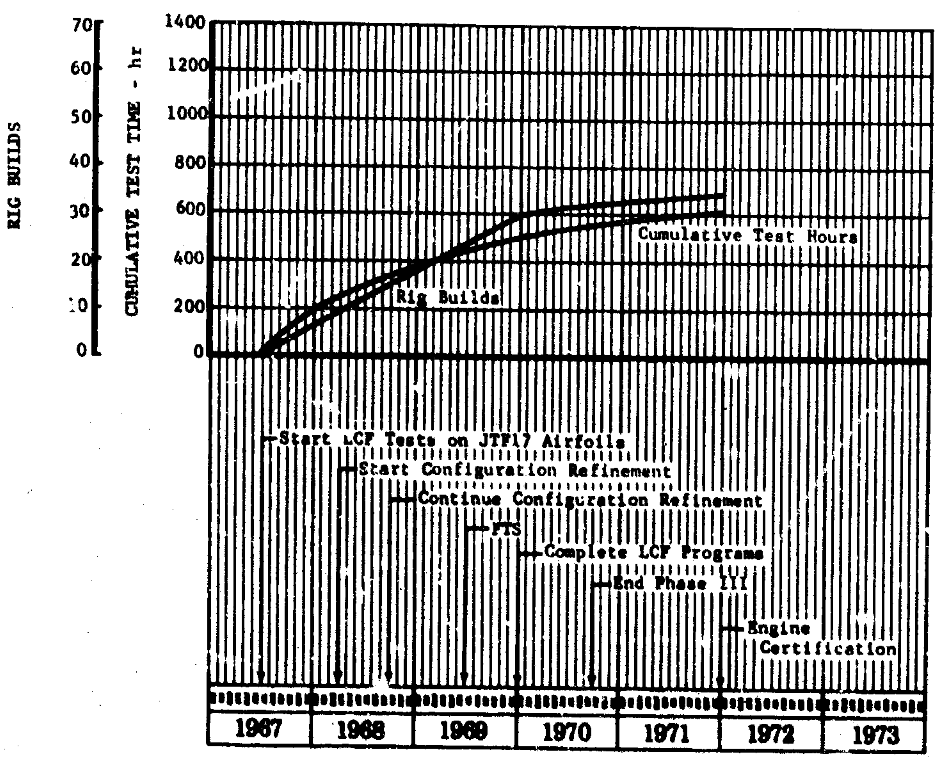

Figure 57. Airfoil Thermal Fatigue Rig FD 16510 EII

Data recording is accomplished by the automatic data recording system, and the test results are reviewed before proceeding to the next data point. Data reduction results in a plot of airfoil metal temperature across the chord at the 50% span location, a plot of cooling effectiveness vs cooling airflow, and an evaluation of spanwise temperature distribution.

(2) Static Airfoil Thermal Fatigue Tests

Low cycle fatigue (thermal fatigue) testing will be accomplished on the 1st-stage blade and vane airfoils to demonstrate low cycle fatigue capability. These tests will be conducted in two phases, i.e., static cascade rig, and the rotating high spool rig. The cascade rig thermal fatigue tests on airfoils will consist basically of baseline runs for the rig. The JTF17 design airfoils will be cycled to failure under engine experienced accelerations and decelerations to establish a baseline for the static test. A similar test will be conducted at an accelerated condition (increased thermal transient), if necessary, to provide a screening test for rapid analysis of new airfoil configurations. Follow-on tests of refinements in cooling configurations and new state-of-the-art developments will be compared against these baselines.

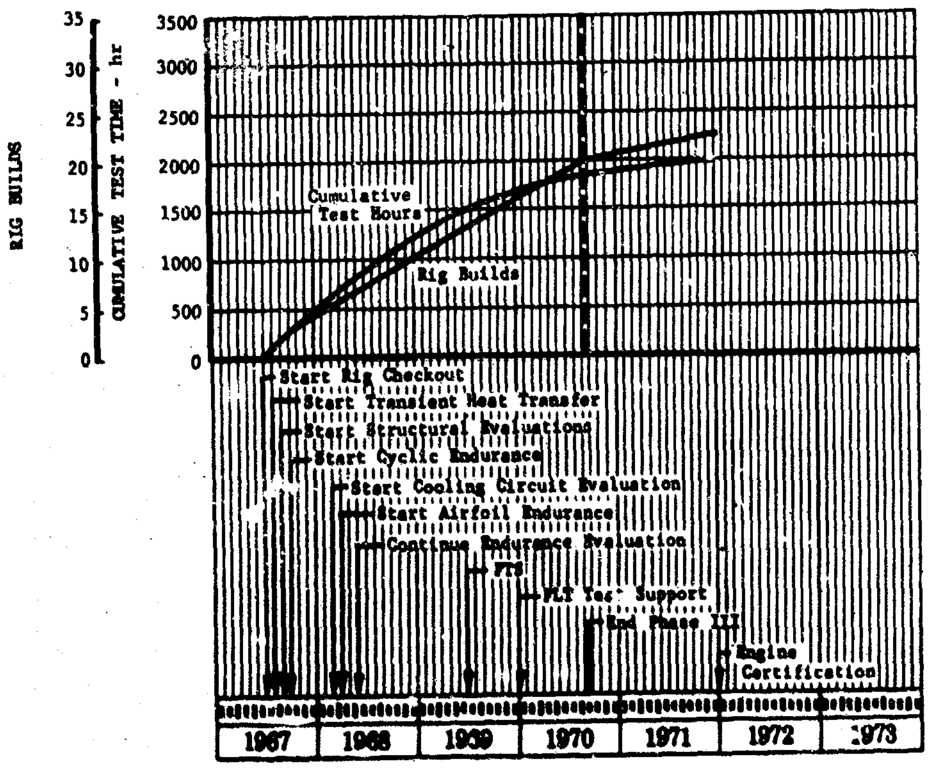

Figure 58. JTF17 Turbine Development Engine (High Spool Rig)

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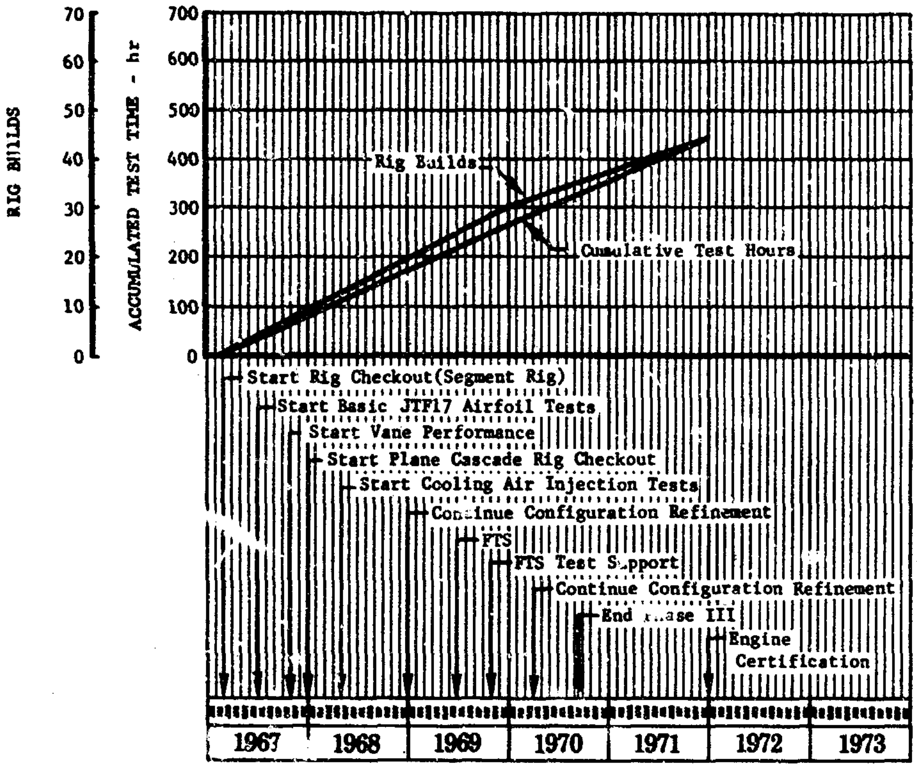

Figure 59. Aerodynamic Cascade Rig (Plane and Annular Segment)

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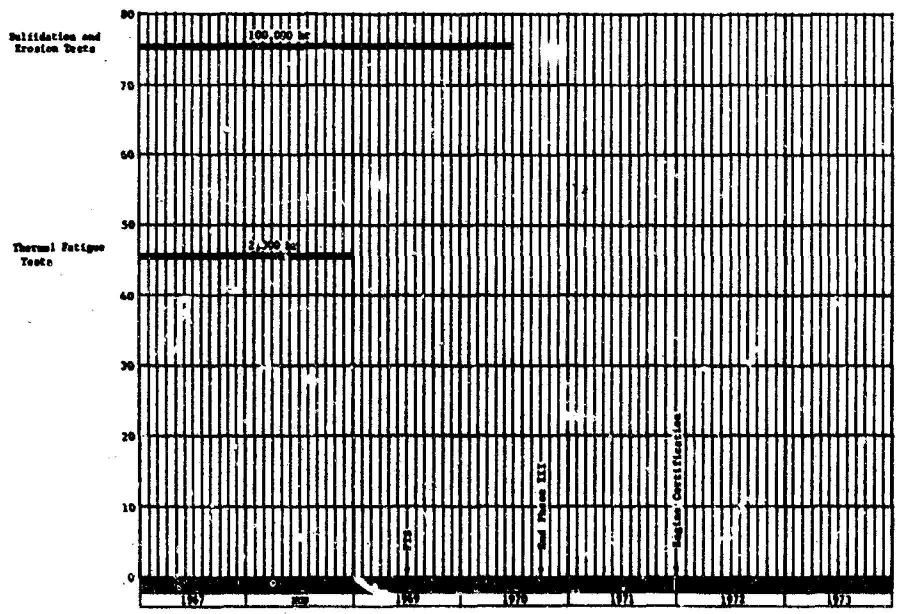

Figure 60. Material and Coating Development Rigs Schedule

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(3) Disk Spin Tests

Spin tests will be conducted on all turbine disks to confirm design yield strength and burst margin. These tests will be conducted on fully machined and loaded heated disks in a spin pit. The test will consist

of a series of incremental rotor speed runs with growth measurements taken at the disk bore and rim. The disk is spun to failure. The results are used to confirm design criteria, update design calculation decks, and verify the burst margin integrity of the disk.

(4) Disk LCF Tests

Disk low cycle fatigue tests will be conducted on all turbine disks in the ferris wheel disk test rig shown in figure 61. The rig is equipped with hydraulic cylinders which apply tension loads to the blades against the rim of the disk. A heating system is available to simulate bore thermals. The disk can be rapidly cycled through its design LCF life to verify accuracy of the design calculation.

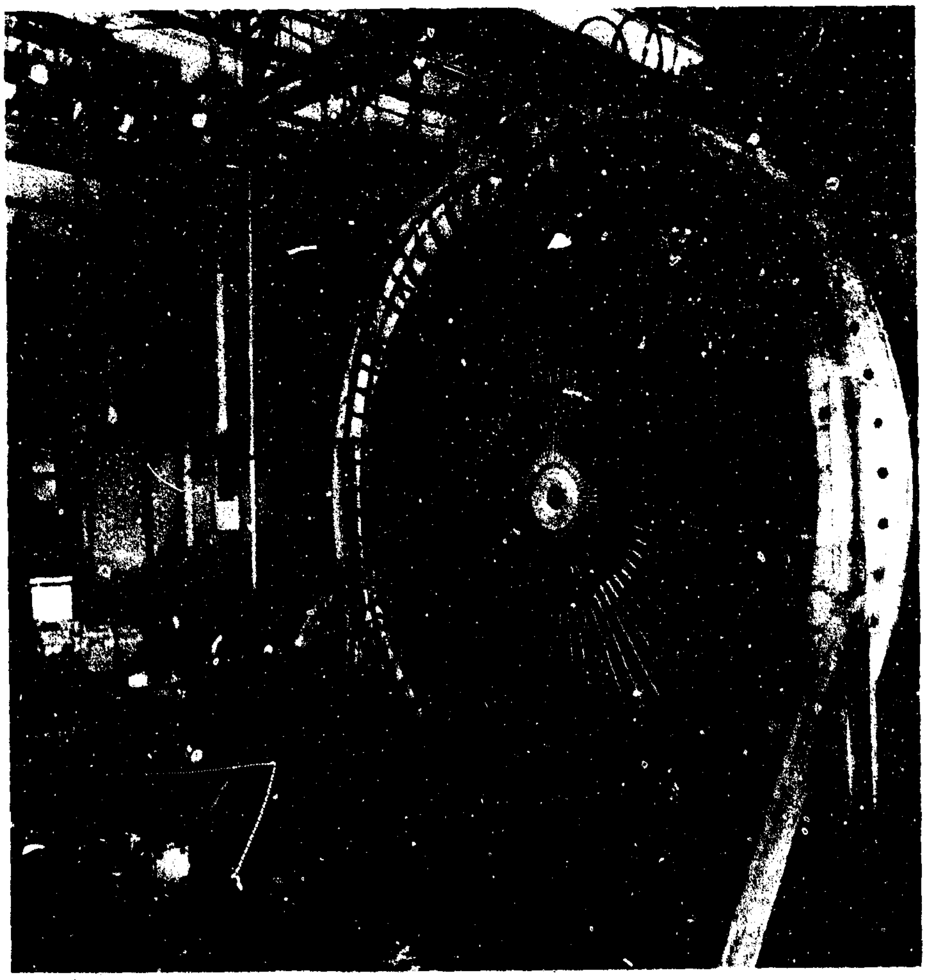

Figure 61. Nonrotating Laboratory Test Rig for Hydraulic Loading of Rotor Disk H-15495-A EII

(5) Transient Heat Transfer Tests

A transient heat transfer test will be run on the 1st-stage vane and blade in the JTF17 High Spool Rig. The purpose of this test is to define the thermals that occur in the airfoils as a result of accelerations and decelerations in the engine, and the effect of the cooling scheme in reducing the airfoil/thermal gradient. This is accomplished by changing

the cooling arrangement of several of the blades and vanes to establish a baseline temperature for the airfoil. The airfoils are instrumented for the test with thermocouples along the leading edge and at strategic locations across the chord. The thermal gradient in the airfoil can be equated to strain and evaluated in terms of thermal fatigue.

(6) Cyclic Endurance Tests

The high spool rig cyclic endurance test will be run to verify the thermal fatigue capability of the high turbine airfoils. The test will consist of rig accelerations and decelerations simulating engine conditions from idle to maximum power. The turbine inlet temperature at the maximum power point will be established by temperature traverse probes to ensure correct profile and temperature level. The automatic control system will be set up to duplicate the cycle at prescribed time intervals. Periodic inspections will be performed to determine the integrity of the rotating parts. Added information will be made available through the use of surface temperature measurement instrumentation on the airfoil that will allow for refined calculations of actual combined stress.

(7) Cooling Circuit Performance Tests

Cooling circuit performance tests will be conducted in the rig to determine the overall efficiency of the cooling system. The test will consist of measuring the pressures and temperatures in the engine case cooling passages to determine leakage losses, hot gas mixing, and adequacy of supply. The test will encompass both blade and vane cooling circuits. Fixed orifices simulating the cooling flow to the 2nd-stage airfoils will be included to produce realistic data in the test. Rotating seal clearances in the cooling system will be evaluated.

(8) Structural Tests

Blade and disk stress evaluation tests will be run in the high spool rig to confirm structural and vibratory design criteria. Strain gages will be installed on the disk bore, web, and rim, and on the blade roots in the extended neck area. The rig will be run at design rotor speeds and the data evaluated for definition of critical vibratory modes and stresses. Slip rings are used on the rotor to provide data on the rotating parts.

(9) Airfoil Endurance

Airfoil endurance tests will be run to confirm the creep life and erosion life of the airfoils. This test will consist basically of long term steady-state running at sea level takeoff temperatures. Periodic inspections will be made to determine the integrity of the turbine and the rate of creep in the airfoil.

Erosion and sulfidation tests will be conducted to determine the durability of the airfoil coating system. Recoated airfoils will be used to determine integrity of the recoating application on cleaned and stripped blades and vanes. The test will be run with high sulfur content fuel and with salt injection as required.

(10) Aerodynamic Tests

Basic airfoil performance of the controlled vortex JTF17 first-stage turbine airfoils will be run to confirm performance parameters used in the design. These tests will be conducted both in the annular segment rig in the Plane cascade rigs. Total and static pressure measurements will be provided with transonic traverse probes capable of both radial and circumferential movement. Wall static pressures will be imbedded in the airfoil skin to define boundary layer conditions around the airfoil.

Additional performance tests will be conducted on refined solidity configurations, and recambered airfoil configurations.

(11) Materials and Coating Development

Materials and coating development currently in process will be continued. Additional testing will be conducted consisting of:

1. Coating "screening" tests for oxidation/corrosion and sulfidation resistance
2. Thermal fatigue evaluations of new candidate materials
3. Quality control tests to determine uniformity of thermal fatigue properties resulting from:
   a. Heat-to-heat variations in material
   b. Heat treatment variations in materials
   c. Grain size effects
   d. Forging technique tolerances.

(12) Support Tests for FTS and Certification

Prior to the JTF17 engine FTS test, a turbine configuration will be selected to meet the engine performance and durability goals. This configuration will be thoroughly evaluated in engine and rig tests prior to building the FTS engine.

Certain design substantiation tests will be conducted in rigs during Phase III to substantiate design requirements which are not a part of the FTS test requirement. These are as follows:

1. Blade containment - in the event blade failure has not been encountered in engine development testing, first stage blade containment tests will be conducted in the high spool rig. For these tests the rig will be fitted with a representative duct burner assembly to simulate the complete engine configuration.
2. Low Cycle Fatigue - Tests will be conducted on all turbine disks in the "Ferris Wheel" rig to certify the 20,000 cycle LCF capability of each disk.
3. Structural Integrity - Tests will be conducted on turbine cases and bearing supports to verify spring rates and deflection parameters and confirm critical speed margins in the rotors.

5. Augmentor

a. Introduction

(1) Background

The JTF17 engine is a twin spool turbofan engine utilizing fan stream augmentation that is designed specifically for powering the SST aircraft to a sustained Mach 2.7 supersonic cruise. The thrust of the fan stream is augmented by raising the stream temperature with a duct heater. The augmentor, shown schematically in figure 62, consists of a diffuser, combustor, two-zone fuel injection system, cooling liners (or heat shields) and a variable area exhaust nozzle. Further details concerning the augmentor are contained in Volume III, Report B, Section IID.

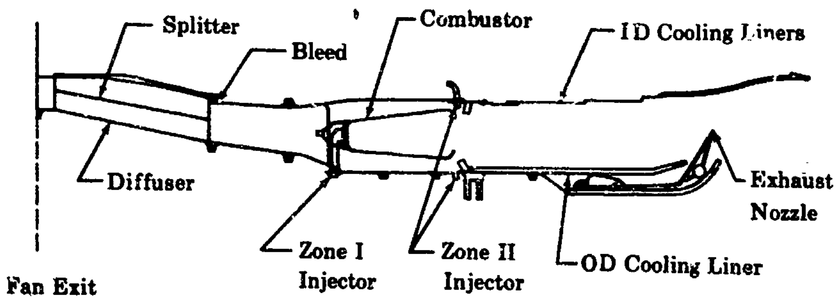

Figure 62. JTF17 Augmentor Schematic FD 16838 EII

The air is supplied to the duct heater from the fan through the diffuser, which reduces the velocity and raises the static pressure. Part of the air then passes through the combustor and is used to burn the fuel that is injected through the Zone I system. The remainder of the air bypasses the combustor, mixes with the combustor discharge gases and flows out of the duct through the exhaust nozzle. For high augmentation levels this bypass air is used to burn fuel from the Zone II fuel nozzles. Combustion of the Zone II fuel occurs only when combustion is presented in the combustor (i.e., Zone II fuel-air mixture uses the flame of Zone I combustor to pilot combustion). The inner and outer duct cases are protected from the combustion gases by liners which are cooled by a portion of the bypass air.

The unique feature of the JTF17 augmentor is the use of the "ram induction" combustor concept as in the main gas generator combustor. In this concept the dynamic pressure of the velocity head of the air flowing past the combustor and the static pressure across the combustor are used to drive the air into the combustor.

This feature reduces the amount of diffusion (and reacceleration) and lowers total pressure loss of the system. Use of the ram-induction combustor provides efficient combustion at all fan exit conditions (i.e. temperature and pressure) within the operating envelope with relatively low pressure loss of the fan stream.

The augmented turbofan cycle performance is sensitive to the performance of the duct heater; an increase in combustion efficiency of 1% at a fuel-air ratio of 0.025 will lower engine Mach 2.7 cruise TSFC 0.74% and result in a typical payload increase of 1040 lb over typical 4000 statute mile stage lengths. A decrease of duct pressure loss of 1% will reduce engine Mach 2.7 cruise TSFC 0.24% and increase typical payload by 350 lb. It is quite apparent that high duct heater performance must be obtained if the SST aircraft is going to be profitable in airline use. The structural integrity of the augmentor parts must also be such as to allow high TBO and not contribute to excessive aircraft down time. The augmentor must provide suppression of fan noise and minimize air pollution due to combustion smoke formation.

The development test program described will provide the levels of augmentor performance and structural life that are necessary to ensure the JTF17 engine will meet its requirements. This section includes program objectives, description of the test rigs, component test programs and schedules. The testing of the duct heater will be carefully integrated with other engine components, particularly the fan, fuel control system, and the exhaust system to ensure that the augmentor works as an integral part of the whole engine system. The duct exhaust nozzle is being treated as part of the exhaust system and will not be discussed in this section.

(2) State-of-the-Art

Thrust augmentation in the past has primarily been applied to turbojet engines. In cases when turbofan engines have been augmented it has been accomplished by use of a common afterburner-fan burner or "coburner" as in the TF30 and Rolls-Royce Spey. The independent coannular duct heater with its separately choked variable nozzle exhibits quite different operational characteristics. The JTF17 duct heater cycle has been tailored to the SST airplane and has the advantage of longer life and stabilized airflow for optimum inlet matching (see Volume III, Report A, Section IIID). To meet the SST engine requirements of high combustion efficiency and low total pressure loss, the ram-induction duct heater was selected. Results of early tests conducted as part of Pratt & Whitney Aircraft's Independent Research and Development effort indicated that the ram-induction burner could provide high combustion efficiency over a wide range of fuel air ratios while operating at low temperature and pressure.

b. Present Phase II-C Status

A comprehensive augmentor development program was conducted as part of the Pratt & Whitney's Phase II-C effort. A summary of the component testing is shown in table 9.

Table 9. Component Testing Summary

Rig	Description	Information Acquired	Phase II-C Accumulated Hrs.
0.6-Scale Annular Duct Diffuser Rig (Design Verification test)	0.62 simulation of engine duct passage from fan discharge to combustor forward	Diffuser total pressure loss, static pressure recovery, characteristics of flow	96
Full-Scale Annular Duct Heater Rig (Design Verification)	Exact simulation of engine duct flow path from fan discharge to exhaust nozzle inlet	Combustion efficiency Total pressure loss Ignition characteristics Temperature Distribution Parts Integrity	45
Full-Scale Sector Duct Heater Rig (Design Selection Test)	Two-dimensional Simulation (7 inch wide x 11 inch high) of Duct Heater	Combustion Efficiency Combustor Pressure Loss Ignition Characteristics	289
Large Scale Annular Jet Flameholder Rig (Design Selection Test)	Annular Duct Heater Rig Sized for 600 PPS engine used to evaluate jet flameholder duct heater	Total Pressure Loss Combustion Efficiency Bleed Flow Rate	69

The results of the Phase II-C component testing are reported in the following sections:

(1) Duct Diffuser

The diffuser rig simulated the actual duct heater flow path from the fan exit to the duct heater inlet. The rig is described in Paragraph 5e below and shown schematically in figure 63. Total and static pressures were measured at the stations noted in figure 63 to determine the total pressure loss, static pressure recovery, exit Mach number and general flow characteristics. The measurements were taken over a range of inlet Mach numbers and with flat and peaked inlet pressure profiles.

The total pressure loss and the static pressure recovery for the fan duct diffuser are shown in figure 64. The losses are extremely low with a flat inlet profile. This fact is particularly encouraging because the two-stage fan of the JTF17 engine is expected to produce a flat profile at cruise conditions. The diffuser exhibited appreciable tolerance to flow distortion. With peaked discharge profile, the total pressure loss was approximately 2% for inlet Mach numbers corresponding to cruise conditions.

The static pressure recovery data confirmed the low total pressure losses. Even with a severely inboard peaked inlet profile, the static pressure recovery is an acceptable 70%, and approaches 85% with a flat inlet profile. The average Mach number at the diffuser exit (combustor inlet) is shown in figure 65.

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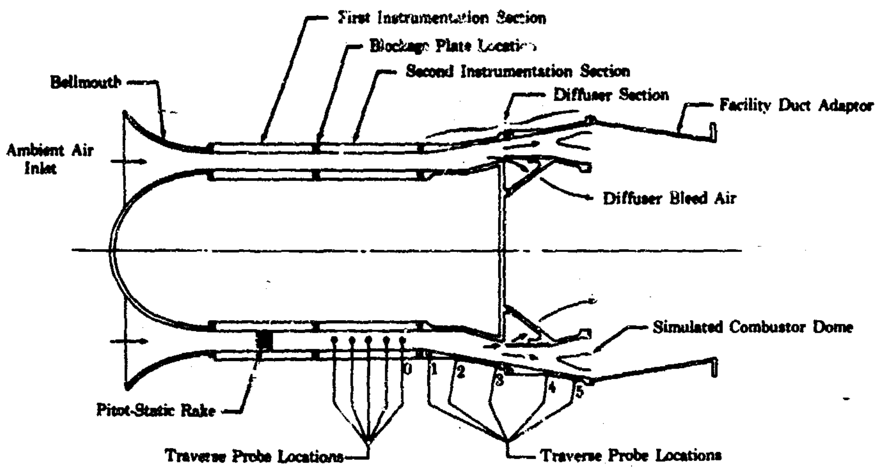

Figure 63. Schematic of 0.6-Scale Duct Diffuser Rig FD 15370 EII

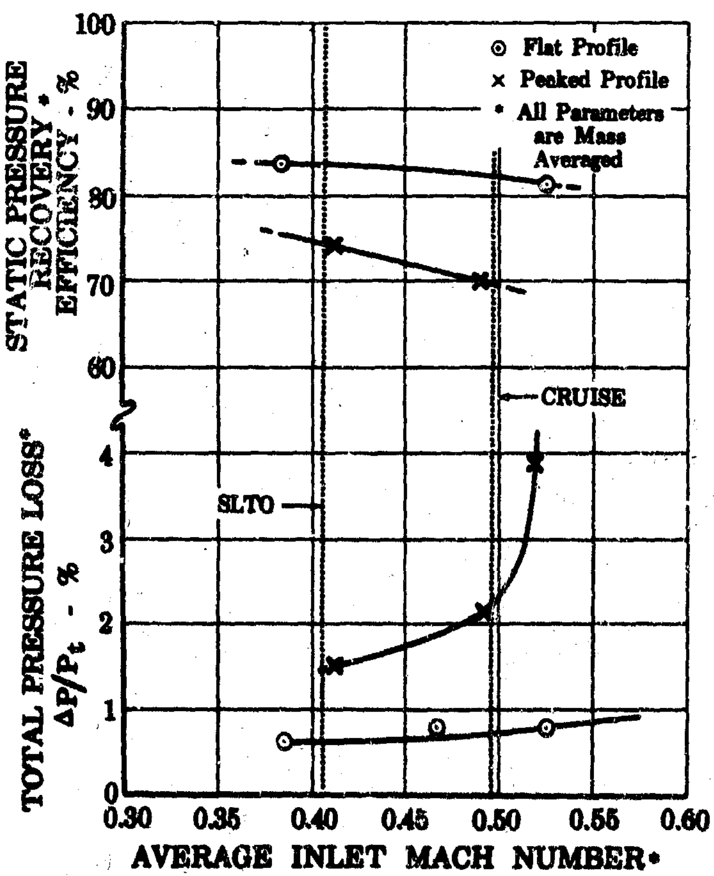

Figure 64. Total Pressure Loss and Static Pressure Recovery for Fan Duct Diffuser FD 17025 EII

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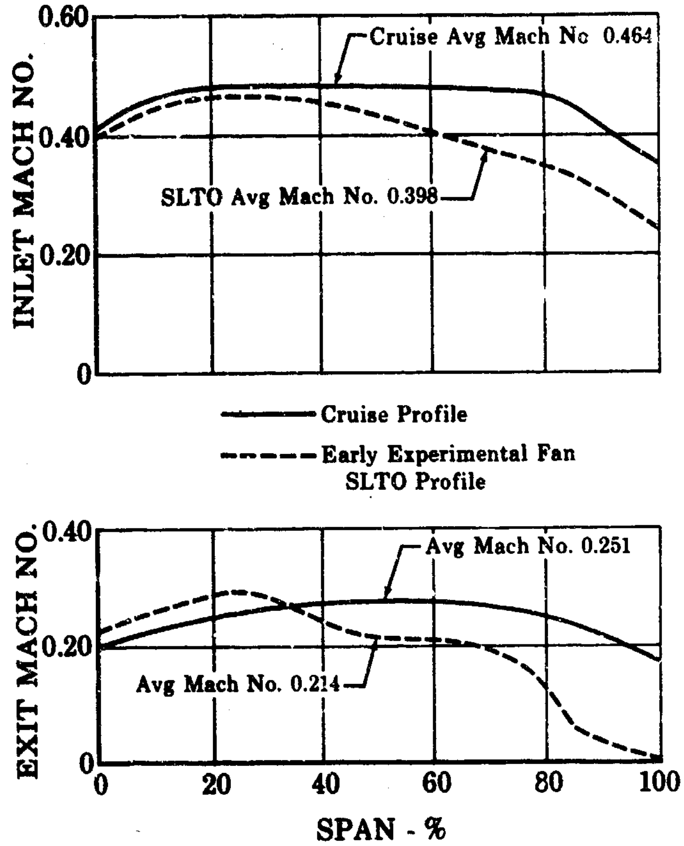


Figure 65. Measured Mach Number Profiles - 0.62 Scale Rig — FD 17021 EII

The higher total pressure loss of the diffuser with the peaked inlet profile is attributed primarily to flow separation at the outer wall. Some evidence of flow separation is shown in figure 66. The region near the outer wall became more deficient in flow after the initial turn, but tended to recover near the entrance to the combustor. This type separation produced a higher total pressure loss, but would not result in operational problems (i.e., instability). Flow separation was not observed with the more uniform inlet profile.

The diffuser losses measured in the full-scale annular duct heater rig with a flat inlet profile (figure 67) corroborate those measured in the 0.6-scale diffuser rig.

(2) Duct Heater

Duct heater testing was conducted on a full-scale annular rig and a 7 x 11-inch sector rig. Both rigs are described in detail in Paragraph 5e below.

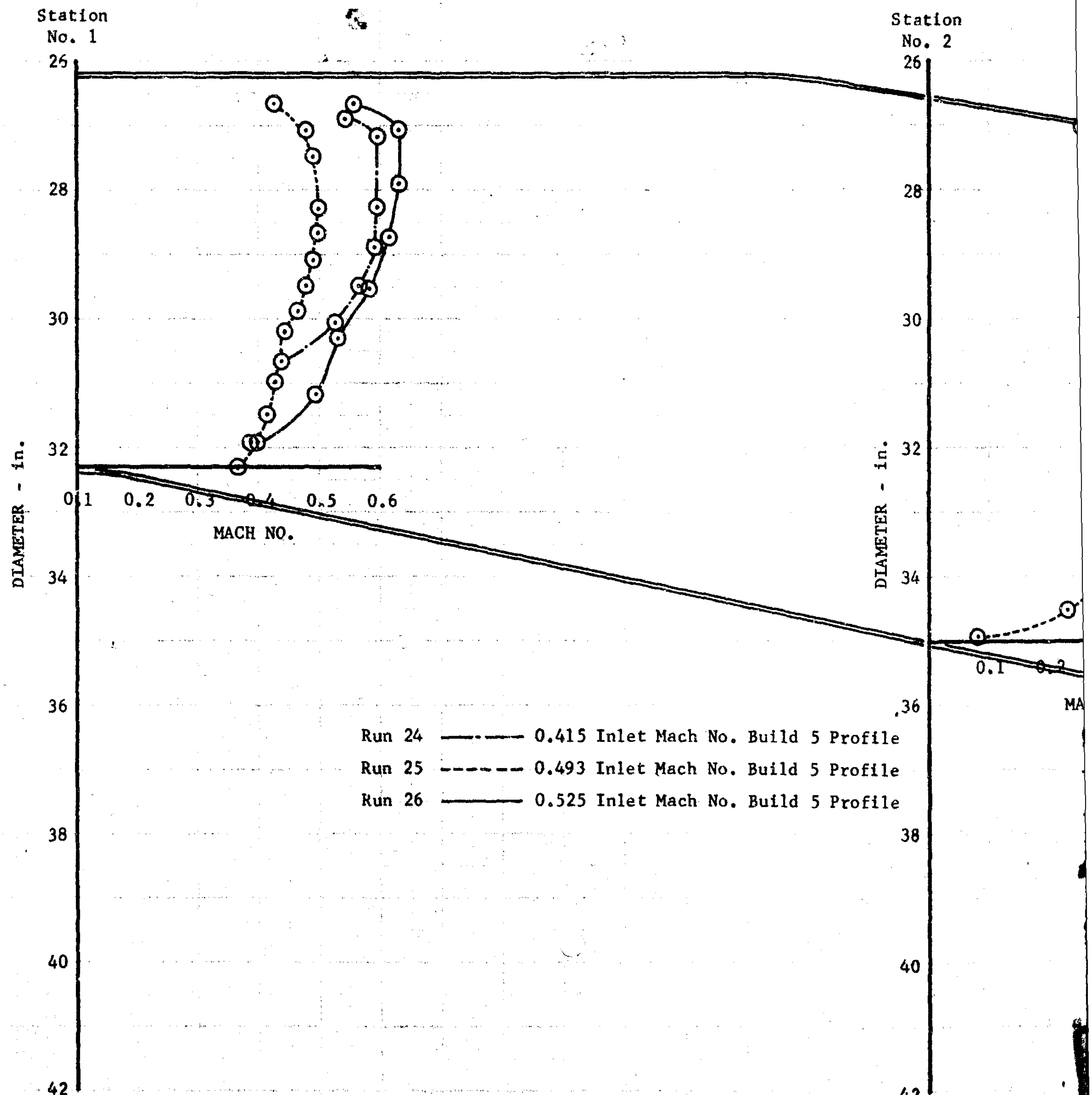
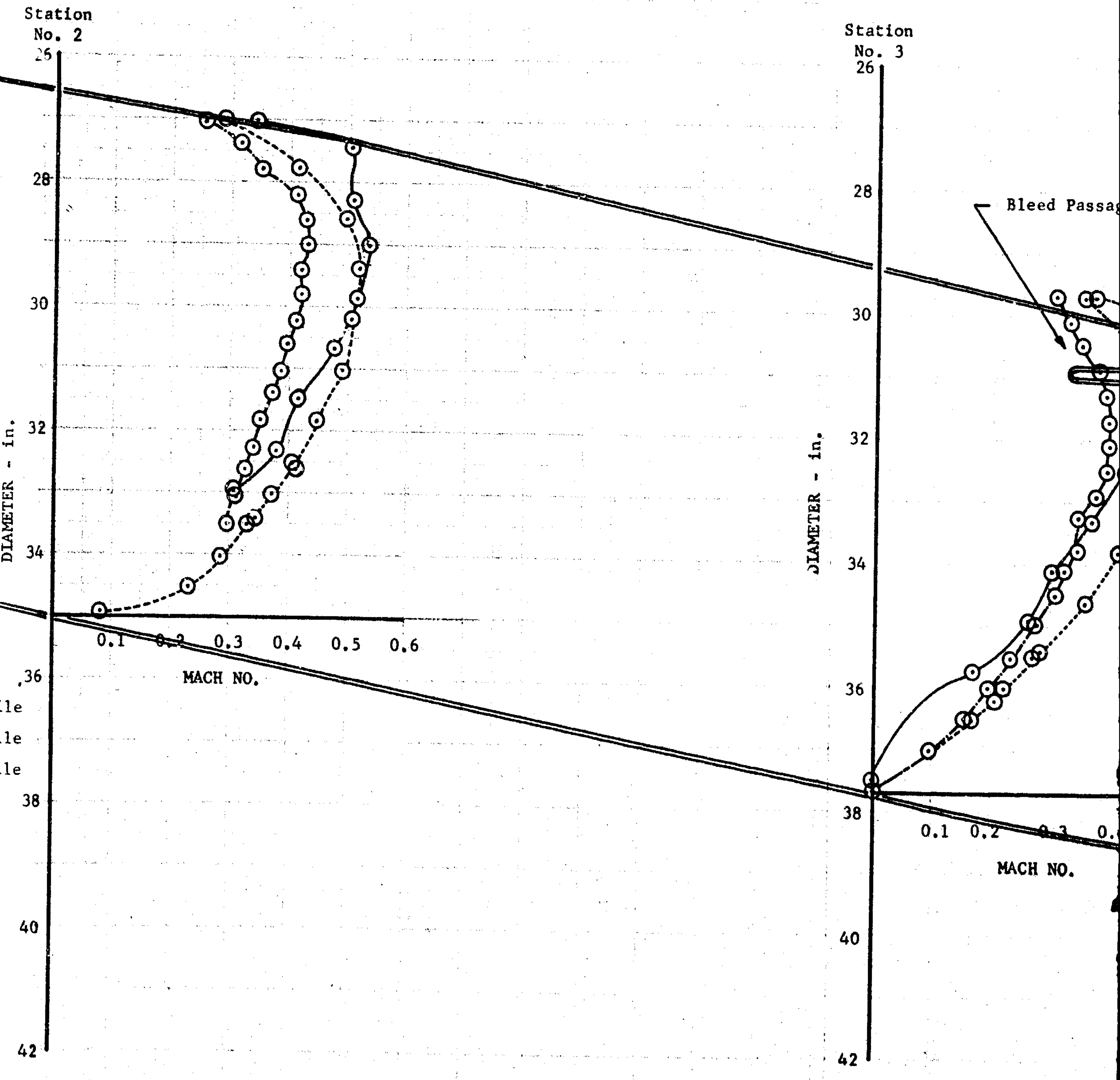
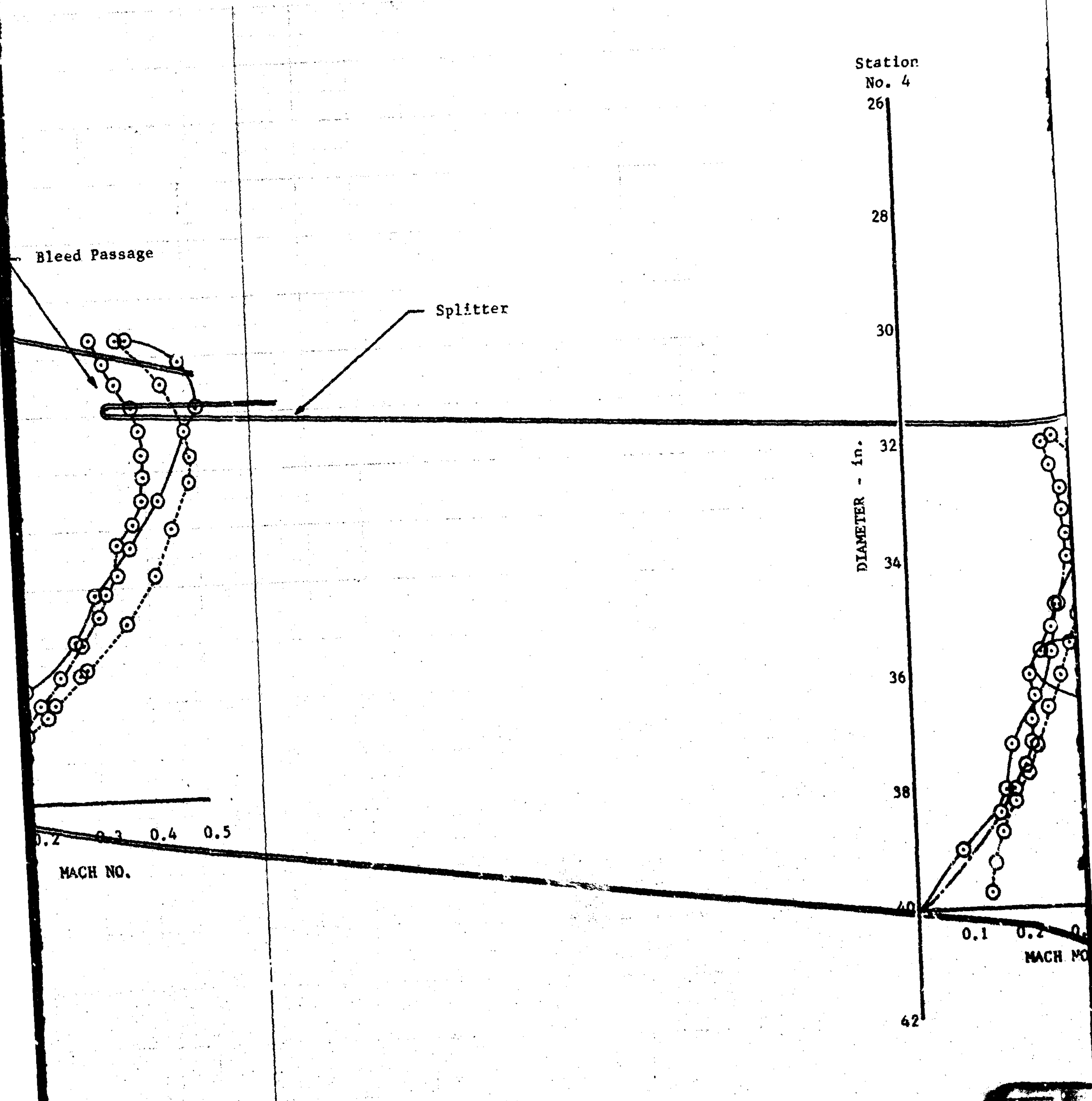
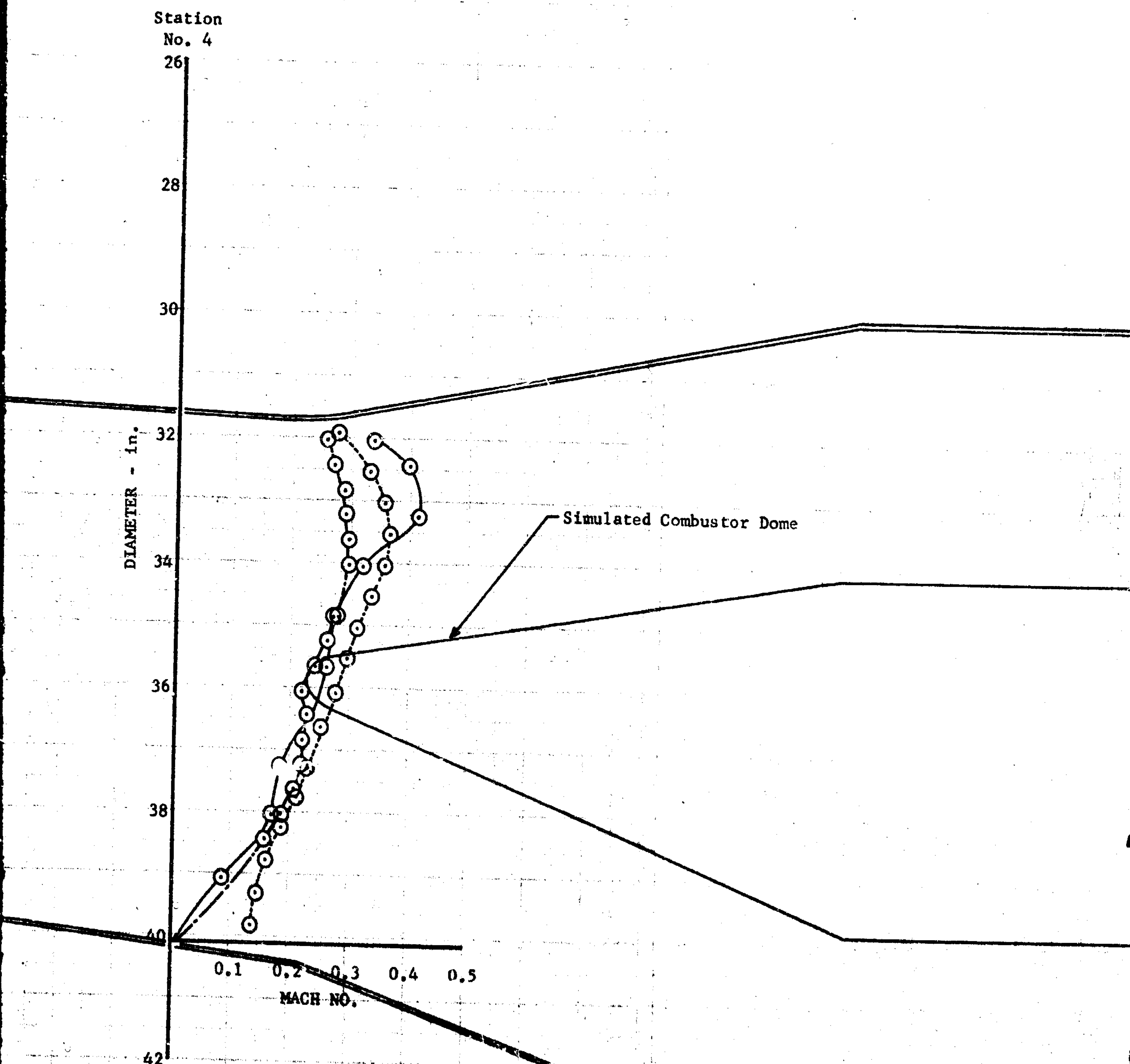


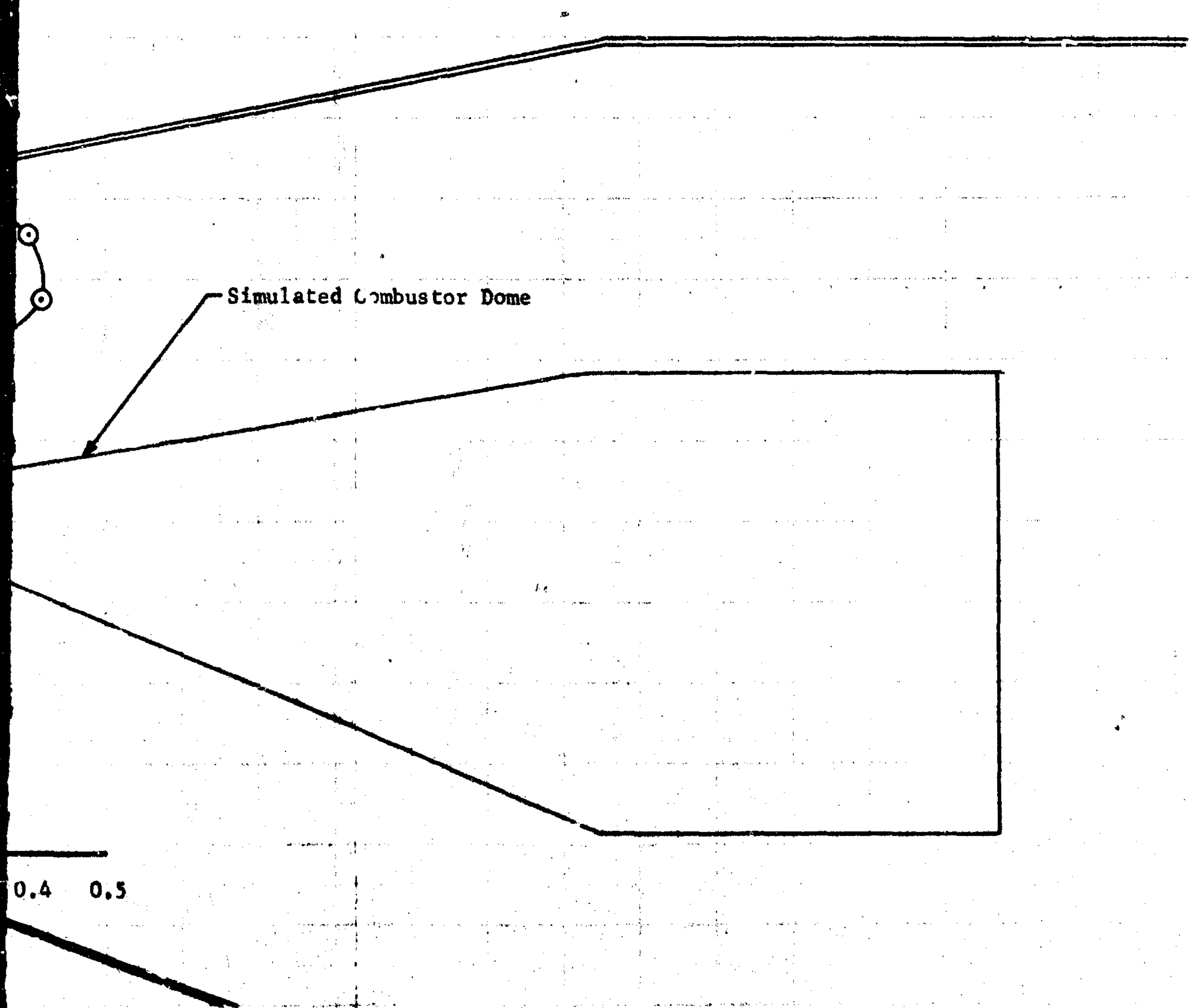
Figure 66. Mach Number Profiles


Station
No. 2
26
28
30
32
34
36
38
40
42
DIAMETER - in.
0.1
0.2
0.3
0.4
0.5
0.6
MACH NO.
le
le
le
Station
No. 3
26
28
30
32
34
36
38
40
42
DIAMETER - in.
Bleed Passa
0.1
0.2
0.3
MACH NO.


Station
No. 4
Bleed Passage
Splitter
DIAMETER - in.
26
28
30
32
34
36
38
40
42
0.2
0.3
0.4
0.5
MACH NO.
0.1
0.2



Station
No. 4
26
28
30
32
34
36
38
40
42
DIAMETER - in.
Simulated Combustor Dome
0.1
0.2
0.3
0.4
0.5
MACH NO.



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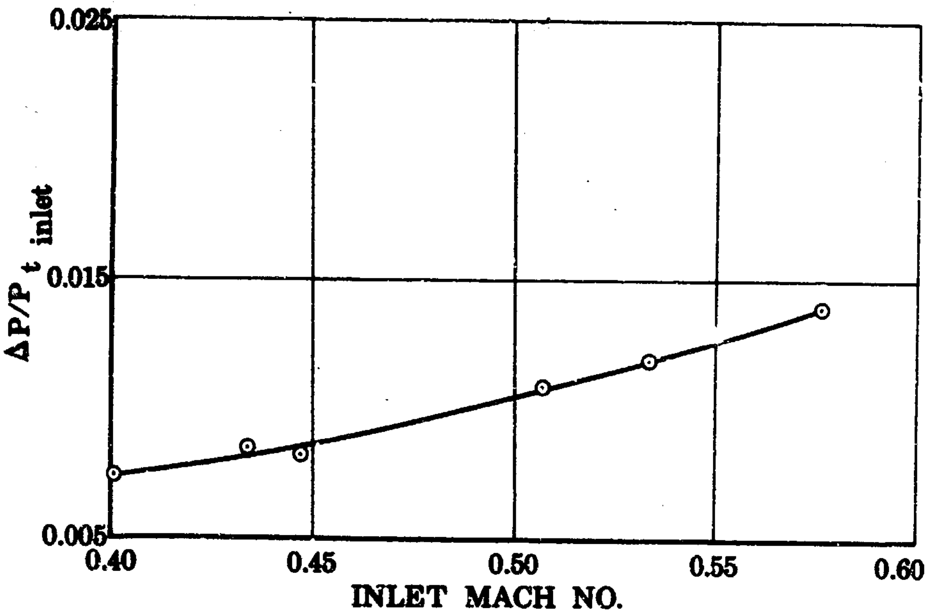


Figure 67. JTF17 Full-Scale Duct Heater Rig Total Pressure Loss for Diffuser Section

FD 17023
EII

(3) Annular Duct Heater Rig

The annular duct heater rig was an exact duplication of the engine fan passage from the plane of the fan discharge to the plane of the exhaust nozzle inlet. The rig is shown schematically in figure 68. The instrumentation probe shown in this figure was used to determine the total pressure loss, the combustion efficiency and coolant flow rates. The combustion efficiency was determined from the actual temperature rise and the metered fuel/air ratio. This efficiency was "thrust weighted" using the outlet temperature and pressure profile as described in Volume III, Report A, Section IIID.

The full-scale annular duct burner was tested for a total of 45.0 hours. The range of simulated flight conditions at which the burner was tested is listed in table 10.

Table 10. Simulated Flight Conditions

Parameter	Maximum	Minimum
Burner pressure, psia	40.0 (sea level)	11.0 (60,000 ft)
Inlet temperature, °F	650	270
F/A ratio	0.058	0.001

The condition of the duct heater after test, as shown in figure 69 was excellent; no evidence of overheating existed and a minimum of carbon was deposited inside the dome. The turbulators on the outside of the annulus were in good condition; however, the outer vane of several of the inner turbulators overheated. The inner liner was adequately cooled with no sign of overheating. At all conditions tested, approximately 6.0 to 8.5% of the total airflow entered the inner cooling liner.

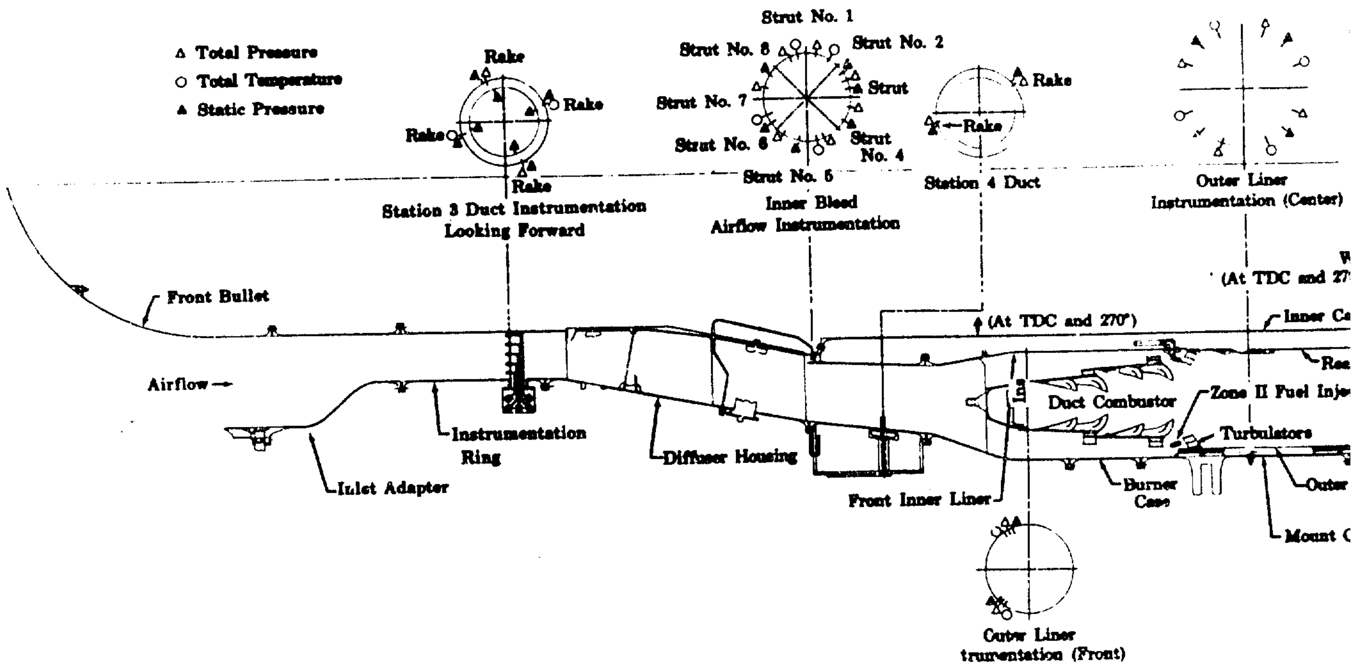
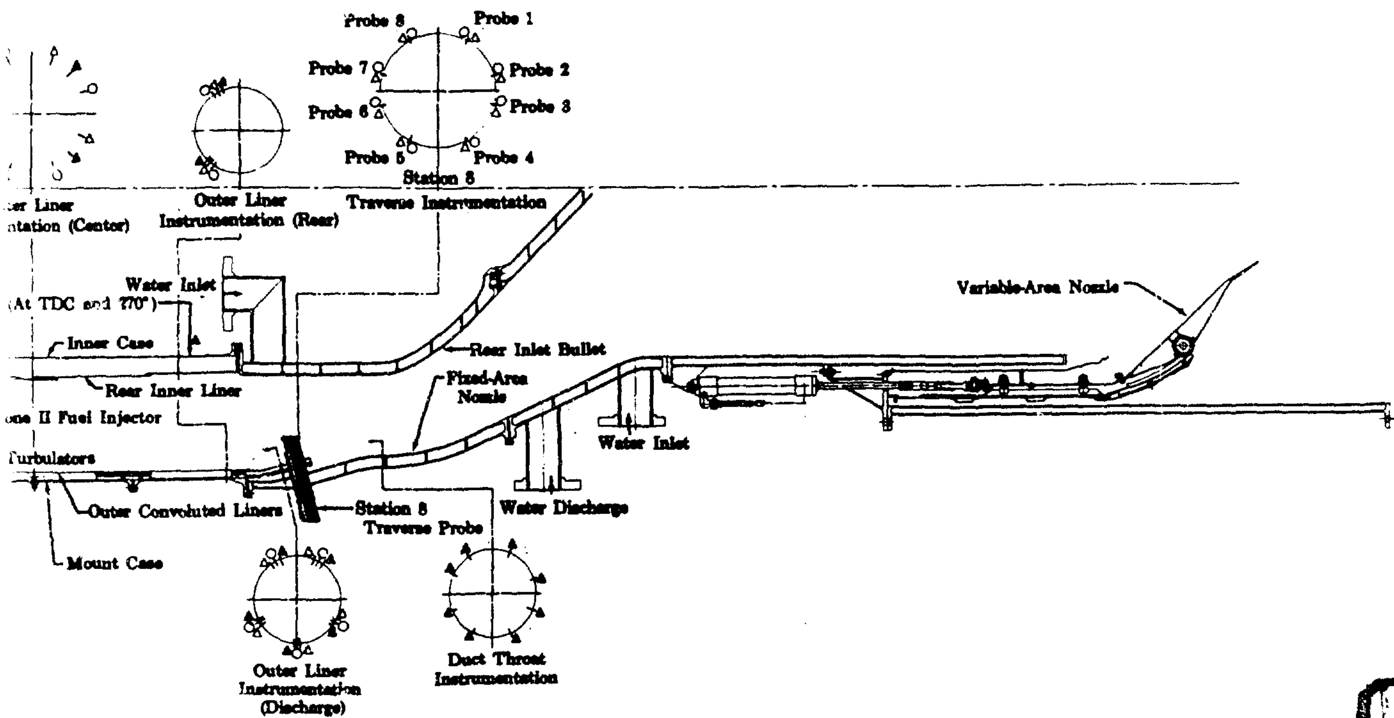


Figure 66. Annular Duct Heater Rig Instrumentation Schematic



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FD 15374A
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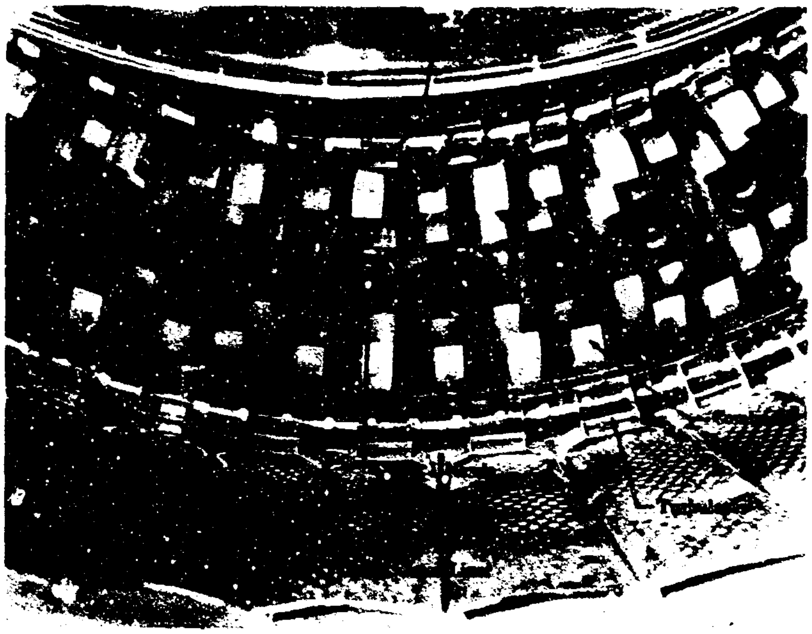

Figure 69. Full-Annular Duct Heater After 45.0 Hours of Testing FD 15302A EII

The OD liners were adequately cooled. Approximately 7.5 to 11% of the total airflow entered the outer liners. Of this, 2.5 to 3.5% of total airflow discharged from the rear cooling liners. The remaining air flowed through the front liner apertures. Some intermediate and rear liners did, however, crack during the tests. The cracks in these liners were attributed to stress concentrations and vibration resulting from pressure oscillations. Figure 70 shows typical liner failures.

The design of the OD liner segments has been revised to eliminate rapid changes of material cross section and to provide more generous radii at the corners of the segments. The forward OD liner segments have been redesigned by increasing the length of the apertures to increase the sound absorption capability of the liner. The design procedure followed is described in *Utvik, et. al., and was incorporated into space between the liner segment and the outer wall of the duct. This provides a higher sound absorption coefficient at low frequencies.

The combustion efficiency of the duct heater as determined by the exhaust temperature measurements is shown in figure 71. The results of the sector rig tests are also shown in figure 71 to demonstrate the excellent agreement with the annular rig results. The duct heater efficiency was over 95% in the expected cruise conditions (Mach No. = 2.7, Altitude = 65,000 ft) and at SLTO. A reduction in combustion efficiency at altitudes above 65,000 ft was also observed in the 7 x 11-inch sector

*Utvik, D. A., H. J. Ford and A. W. Blackman, "Evaluation of Absorption Liners for Suppression of Combustion Instability in Rocket Engines." AIAA Preprint. Propulsion Joint Specialist Conference, Colorado Springs, Colorado, June 1965.

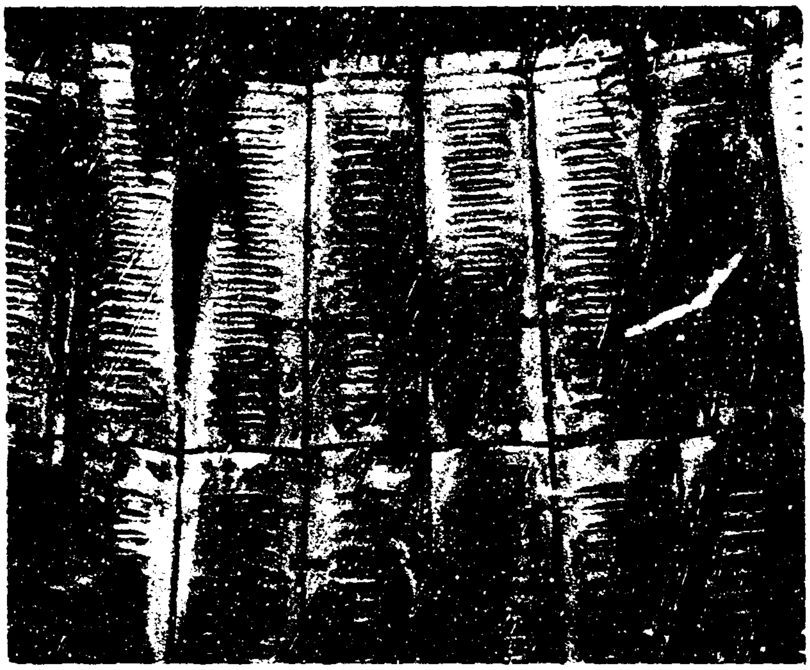

Figure 70. Damaged Outer Cooling Liners

FD 15309
EII

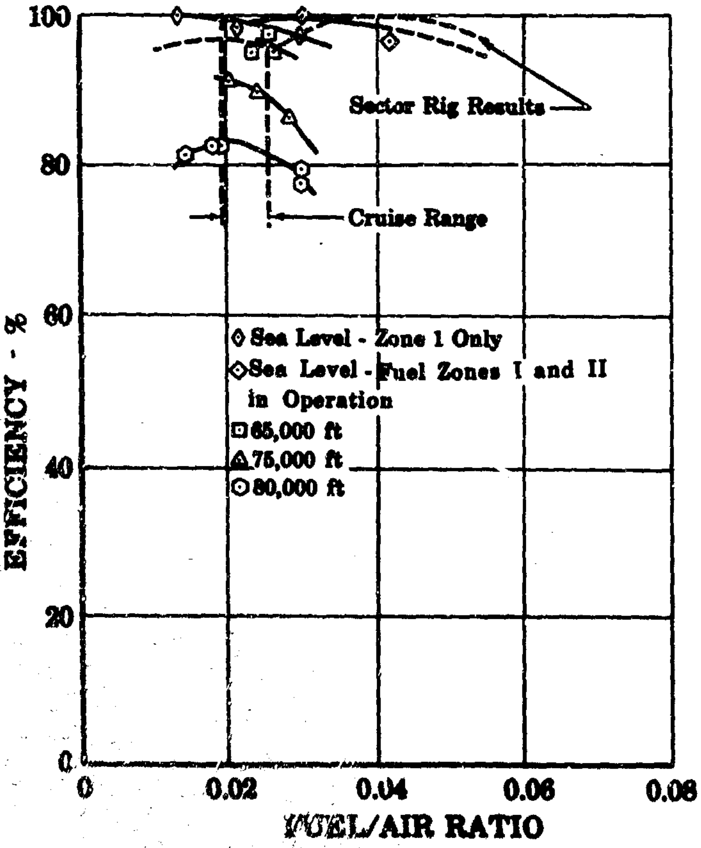

Figure 71. JTF17 Full-Scale Duct Heater Rig Chemical Combustion Efficiency vs Fuel/Air Ratio

FD 17027
EII

rig. Considerable improvement was made to the low pressure operating characteristics of the sector combustor (see 11 x 7-inch sector results) by adjusting the airflow into the combustor and improving flow recirculation in the rear portion of the combustor. Design changes to the front end of the JTF17 duct heater combustor have been made in a similar manner to improve the combustion efficiency at low operating pressures. Temperature and pressure measurements were made across the rig exit plane at F/A = 0.025, Mach No. = 2.7, and altitude = 65,000 feet; these data are shown in figure 72.

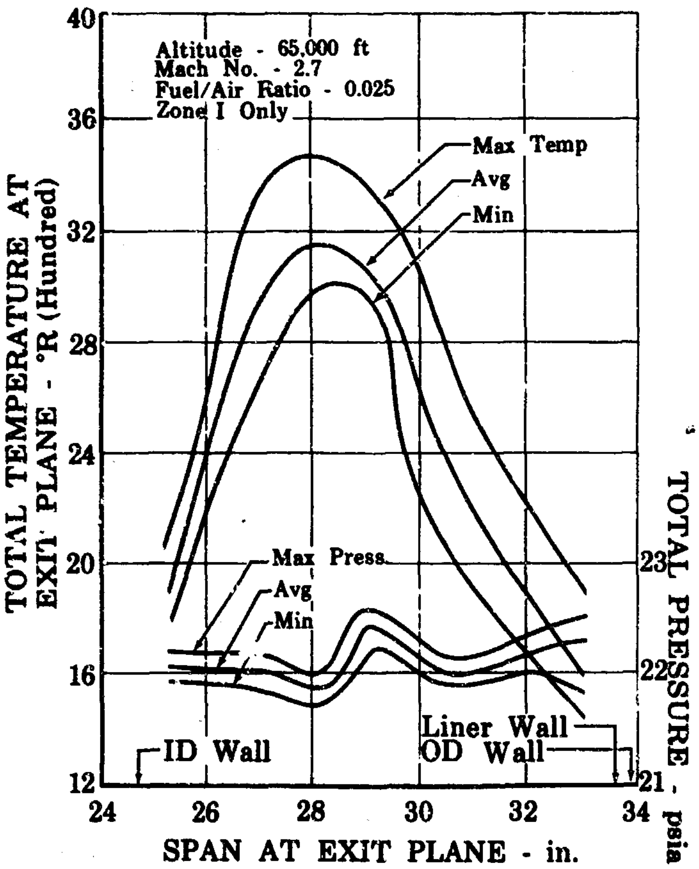

Figure 72. JTF17 Full-Scale Duct Heater Rig Radial Temperature Profiles at Cruise Conditions

FD 17019
EII

Note that the temperature profile peaks close to the inner wall during Zone I only operation because in the original design the combustor was positioned closer to the inner wall to provide air to the OD cooling liners. The outer liner cooling airflow was reduced by decreasing the height of the convoluted liner segments at a time when changing the combustor dimensions was deemed impractical.

The SLTO combustion efficiency at fuel/air ratios above 0.042 were not valid because of nonuniform Zone II fuel distribution. Foreign material in the test stand plumbing supplying the inner Zone II manifold partially plugged the inner fuel injectors.

The cold total pressure loss between the diffuser exit and the combustor exit is shown in figure 73. The loss is less than originally predicted because of the high static pressure recovery associated with the highly efficient diffuser. The overall cold total pressure loss for the duct heater system is shown in figure 74. The results show the additive effects of the diffuser and combustor pressure losses. The lower than predicted total pressure loss was incorporated into the engine performance calculations.

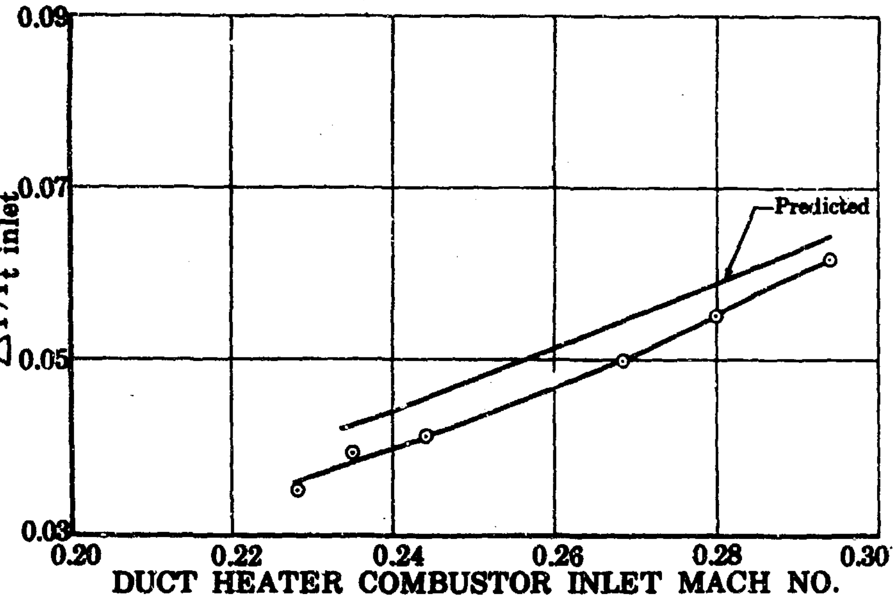

Figure 73. JTF17 Full-Scale Duct Heater Rig Isothermal Loss Through Combustor — FD 17024 EII

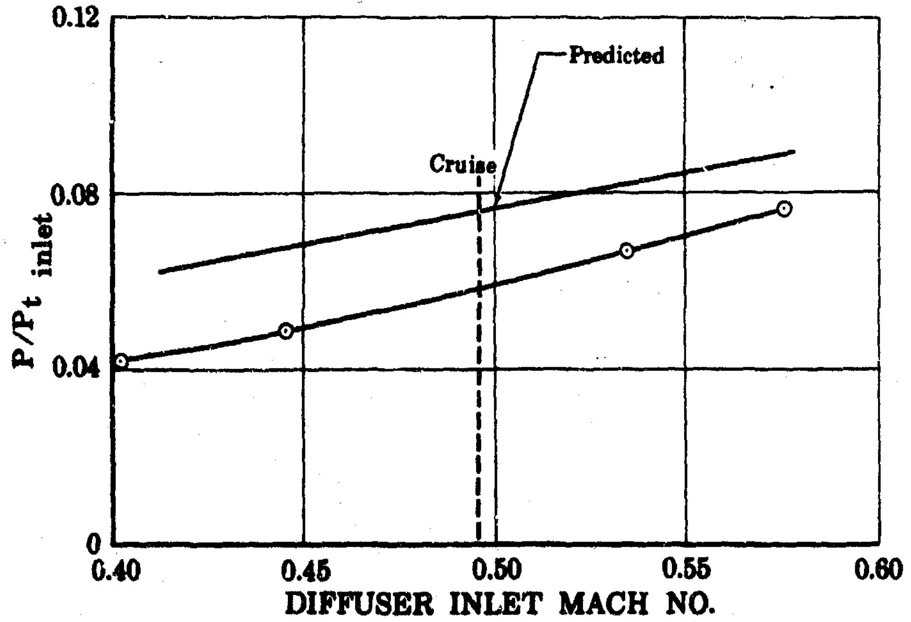

Figure 74. JTF17 Full-Scale Duct Heater Rig Overall Isothermal Total Pressure Loss — FD 17022 EII

The total pressure loss of the duct heater with combustion is shown in figure 75. The hot losses are a strong function of temperature rise and generally were slightly lower than the levels predicted by "Rayleigh line" or momentum change relations where the Mach number is assumed to be the "Reference" Mach number of the duct heater. This result would imply that the principal heat addition is in a region of the combustor where the velocities are lower than the reference velocity.

The duct heater was successfully ignited at all conditions attempted using the 4-joule electrical ignition system planned for the engine. Ignition was accomplished with a very slight rise in duct heater pressure as was desired to avoid fan air flow change; figures 76 and 77. Successful lights were obtained with combustor fuel air ratios of 0.0014 to 0.0048. The phasing-in of Zone II fuel in incremental changes produced no pressure discontinuity (figure 78).

(4) 7 x 11-Inch Sector Rig

The 7 x 11-inch duct heater rig was a full-scale representation of a 7-inch wide segment of the duct heater. The instrumentation used in the rig (shown schematically in figure 79) was conventional pressure, temperature, and volumetric flow measuring devices, except for the measurement of duct heater outlet temperature. Outlet temperature was measured using a variable nozzle of known area operated at choked conditions. The outlet temperature of the duct heater was determined by solving the continuity equation at the plane of the variable area nozzle. By measuring the airflow rate (W), the total pressure (P), and the effective area (A) of a choked nozzle, the total temperature (T) can be calculated using the following equation:

$$T = \left(\frac{\text{Const} \times P \times A}{W}\right)^2$$

The use of this temperature in the calculation of combustion efficiency yielded a thrust equivalent directly. A detailed discussion of the relationship between chemical combustion and thrust equivalent combustion efficiency can be seen in Volume III, Report A, Section IIID.

A total of 443 hours of test time was accumulated on the full-scale sector rig from 1 July 1965 to 21 March 1966 on six basic duct heater models. The terminology used to identify duct-heater sector heater is as follows:

1. The prefix letter indicate the basic model of the combustor.
2. The number following the letter designates the modification of the basic model.

An example of the system would be "E2", or the second modification of the Model E duct heater.

A report of the results of the sector rig tests can be divided into the following sections:

1. JTF17 Duct Heaters
2. Basic Study Duct Heaters
3. Redesigned Duct Heaters

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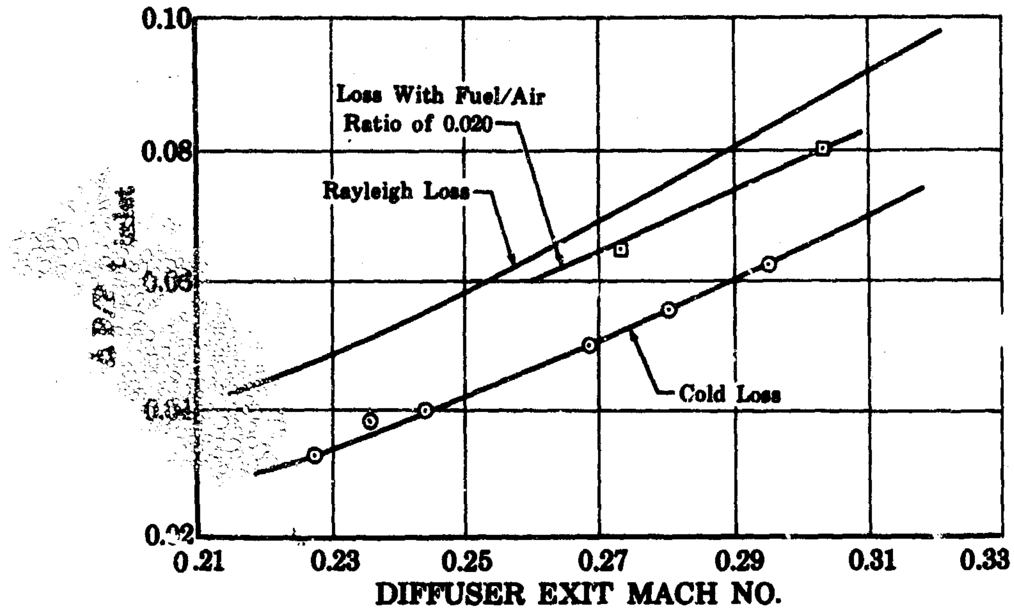

Figure 75. JTF17 Full-Scale Duct Heater Rig Overall Total Pressure Loss at Cruise Conditions — FD 17026 EII

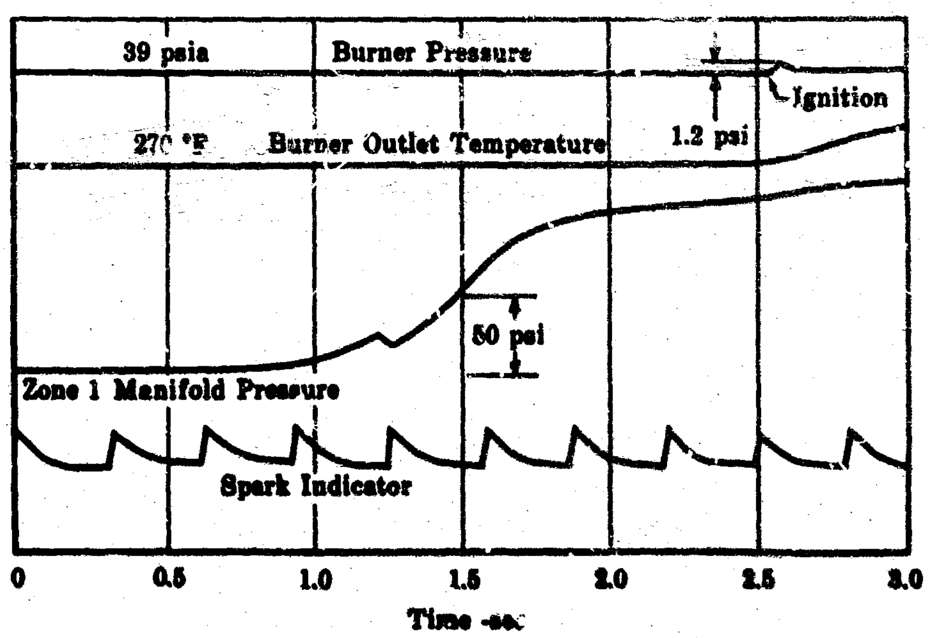

Figure 76. Full-Scale Annular Duct Heater Rig Sea Level Ignition Test Results — FD 15304 EII

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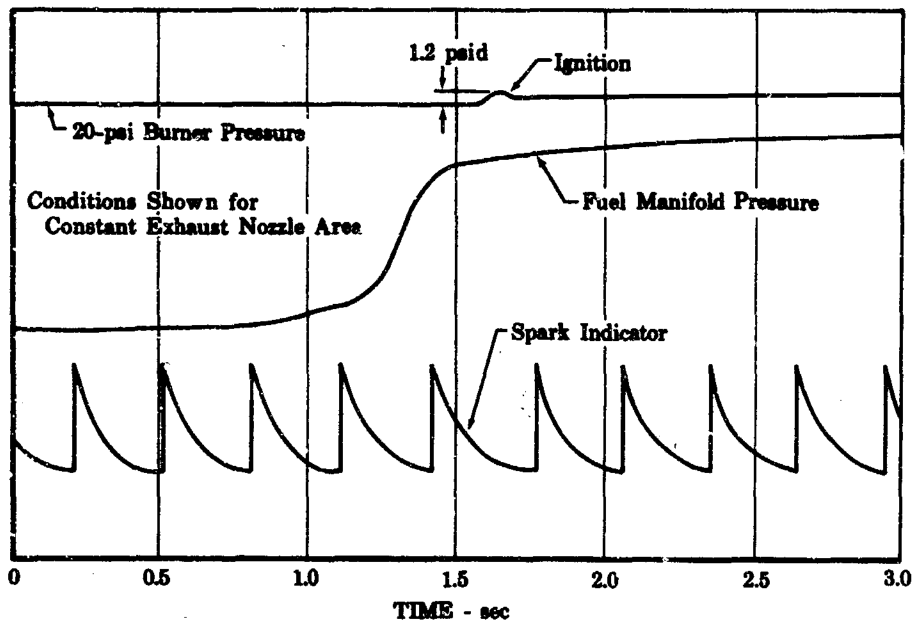

Figure 77. Full-Scale Annular Duct Heater Rig Mach No. 2.7, 65,000 Cruise Ignition Test Results — FD 15303 EII

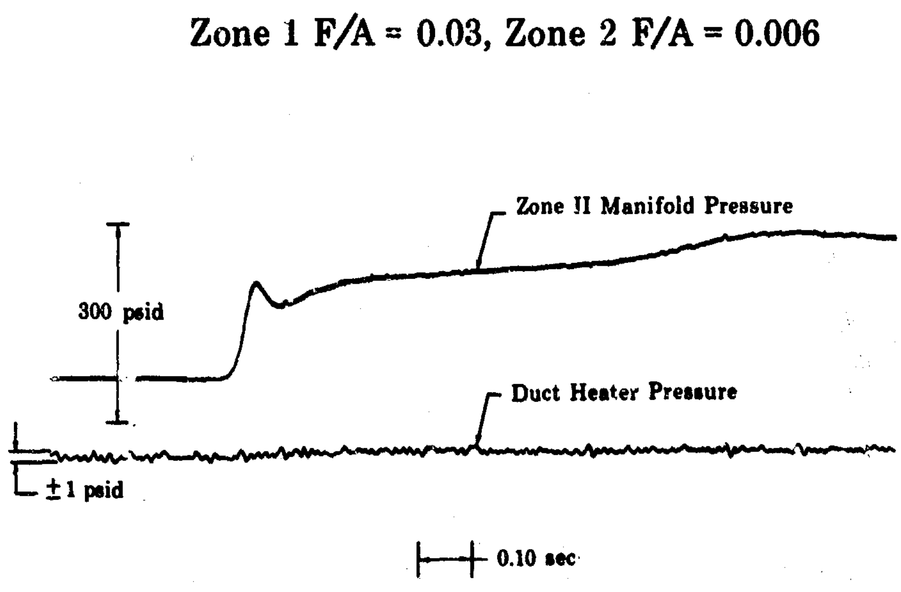

Figure 78. Rate of Duct Heater Pressure Rise With Addition of Zone II Fuel (Rig Data) — FD 14605D EII

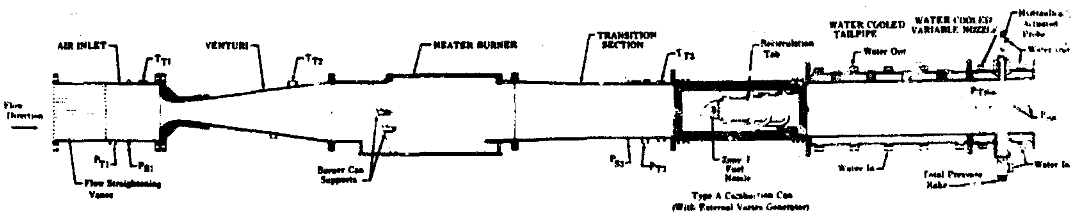

Figure 79. Schematic of Duct Heater Test Section FD 15630 EII

(a) JTF17 Duct Heaters

The combustors discussed in this section were those that either directly contributed to the JTF17 duct heater design or were simple modifications of the basic JTF17 design.

E Model Duct Heater

The E-3 combustor shown in figure 80 was selected as the aerodynamic basis of the first JTF17 augmentor because of its excellent performance at inlet pressures representative of SLTO and Mach 2.7, 65,000 conditions (see figure 81). The operating range of the significant duct heater configurations is listed in table 11. Limitations in facility capability (i.e. the lack of an air cooler in the compressor discharge) prevented testing over a wider range of conditions. No modifications past E3 improved the combustion efficiency or operating range of the Model E heater.

Table 11. Rich Blowout Limits at 9 psia and 200°F Inlet

Configuration	Zone I Only	Zone I & II
E3	0.011	No Zone II Ignition
K13	0.020	No Zone II Ignition
J1	Unable to Burn	No Zone II Ignition
J6	0.025	Beyond Operating Limit (F/A>0.06)
H7	0.015	Beyond Operating Limit (F/A>0.06)
L12	0.013	0.030

Figure 80. Model E Duct Heater Combustor FE 44292 EII

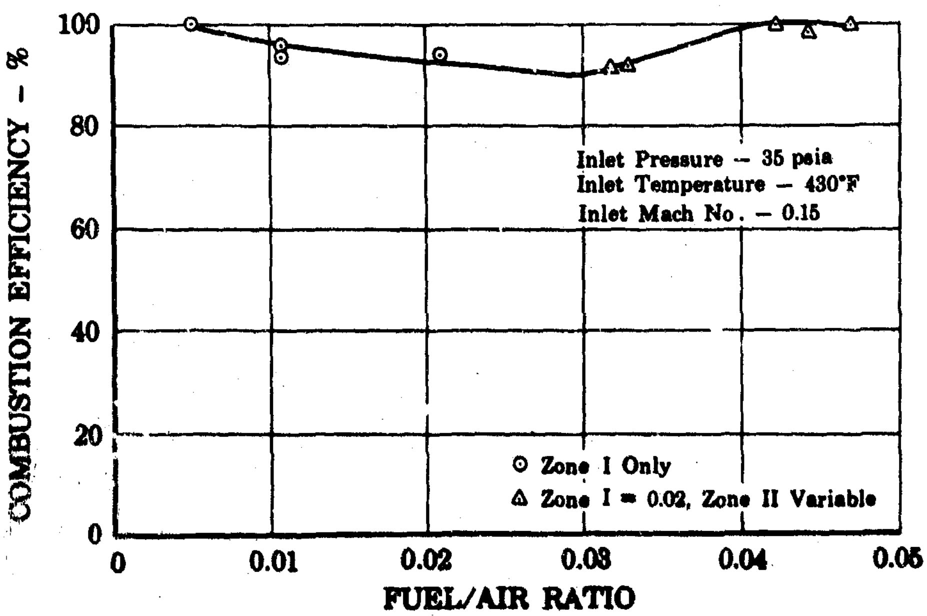

Figure 81. Model E3 Duct Heater Performance FD 16638 EII

K Model Duct Heater

The K combustor shown in figure 82 utilized the basic aerodynamics of the E3 but was modified to redistribute the air circumferentially (the relation of scoops to fuel nozzles was increased from 1 to 1.5:1). This modification was successful in improving the low pressure operation of the E3 heater while maintaining its excellent high pressure combustion efficiency as can be seen in figure 83.

The K13 heater which was an exact simulation of the engine duct heater was used to evaluate the 4-joule electrical ignition system. Consistent ignition was obtained at the 35 psia inlet conditions at fuel-air ratios between 0.001 and 0.005 indicating that the engine duct heater could be ignited without causing insignificant duct pressure change.

Figure 82. Model K Duct Heater

FE 54059
EII

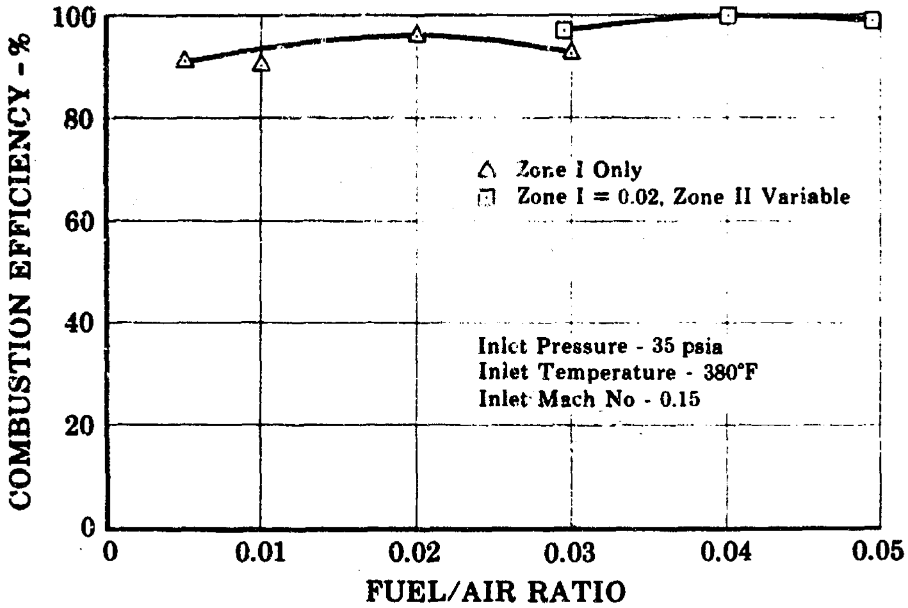

Figure 83. Model K13 Duct Heater Performance FD 16639 EII

A special series of tests were conducted on the K13 heater to determine the pressure dependence of combustion efficiency. Combustion efficiency was measured over a range of fuel/air ratios at 13 and 11 psia. The results of these tests are shown in figures 84 and 85. A significant drop in combustion efficiency was observed at the low fuel-air ratios; this trend was later corroborated in full-scale annular rig tests. No modifications made to the K Model made any appreciable improvement to the low pressure operating characteristics.

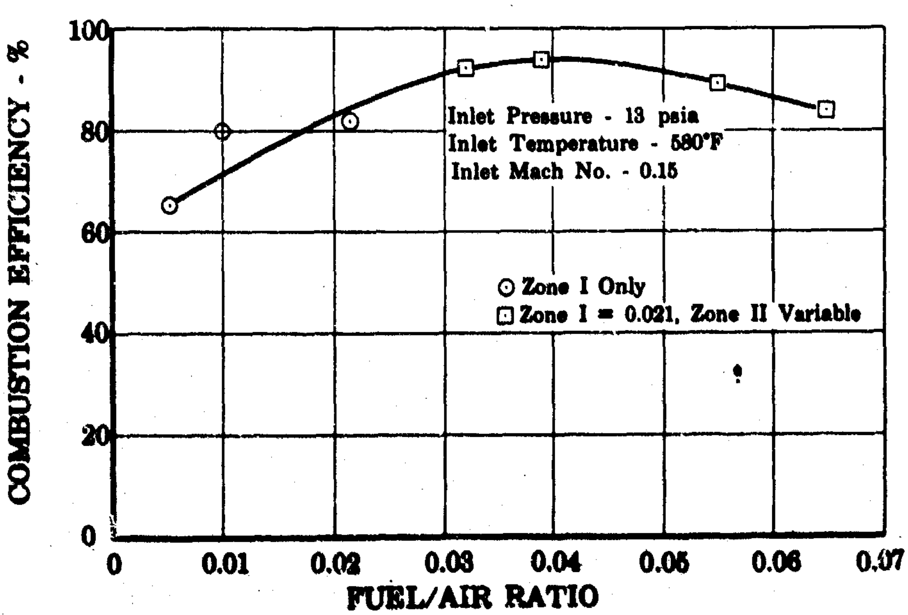

Figure 84. Model K13 Duct Heater Performance FD 16640 EII

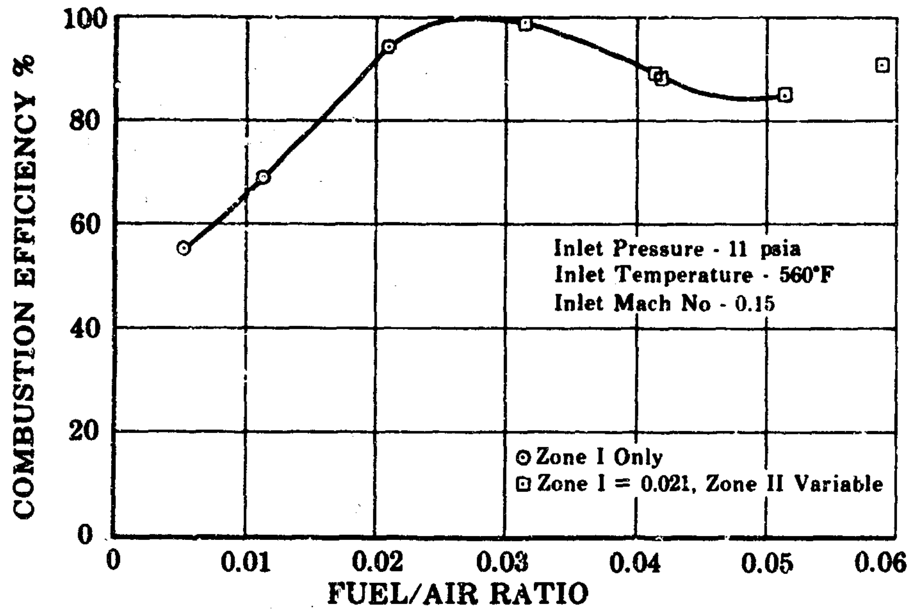

Figure 85. Model K13 Duct Heater Performance FD 16641 EII

(b) Basic Study Heaters

A simplified combustor was conceived to allow more rapid and economical modifications that would enhance the study of basic combustor parameters such as scoop placement, size, turning angle, combustor height, etc. The heater, designated J and shown in figure 86, consisted of flat side plates and circular tubes. Scoop location could be readily changed by drilling holes in the side plates and tacking on the scoops.

A significant improvement in low pressure operating range was made between the J1 and J6 combustor as can be noted in table 11. The following modifications were found to improve low pressure operation of the J Model combustors:

1. Moving initial scoops aft, further away from Zone I fuel nozzles thereby reducing quenching at high fuel/air ratios.
2. Staggering scoops circumferentially to improve shear mixing.
3. Turning the discharge of the aft scoops toward the fuel nozzle to enhance recirculation in the aft region of the combustor.

The modifications were made to the J combustor without appreciably affecting the combustion efficiency at 35 psia (figure 87).

(c) Redesigned Duct Heaters

The sector rig effort was directed at improving the low pressure operation of the duct heater after a suitable configuration had been selected for the initial JTF17 engine testing. Two models were tested to improve low pressure operation and maintain the excellent high pressure combustion efficiency of earlier configurations "E" and "K".

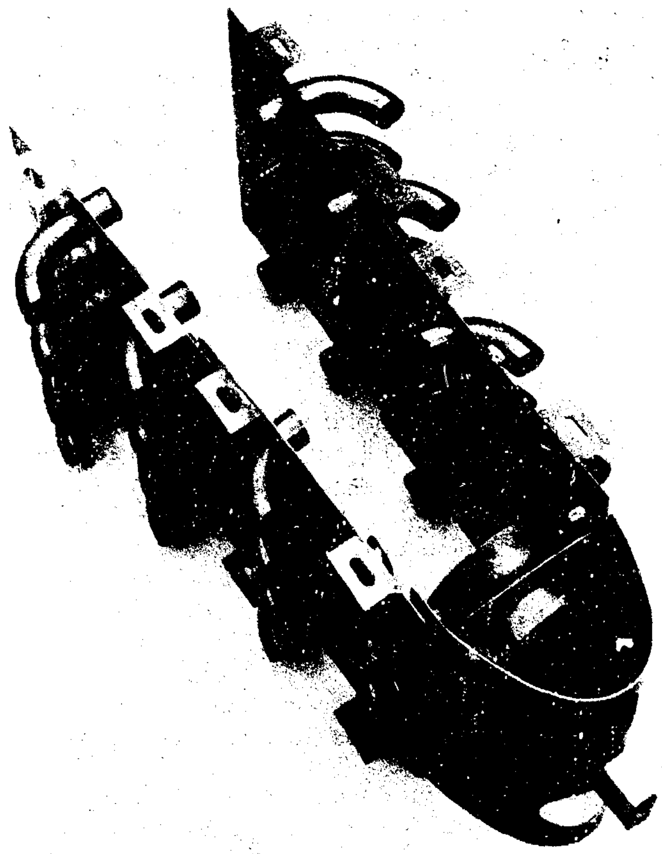

Figure 86. Model J Duct Heater Combustor FE 52470
EII

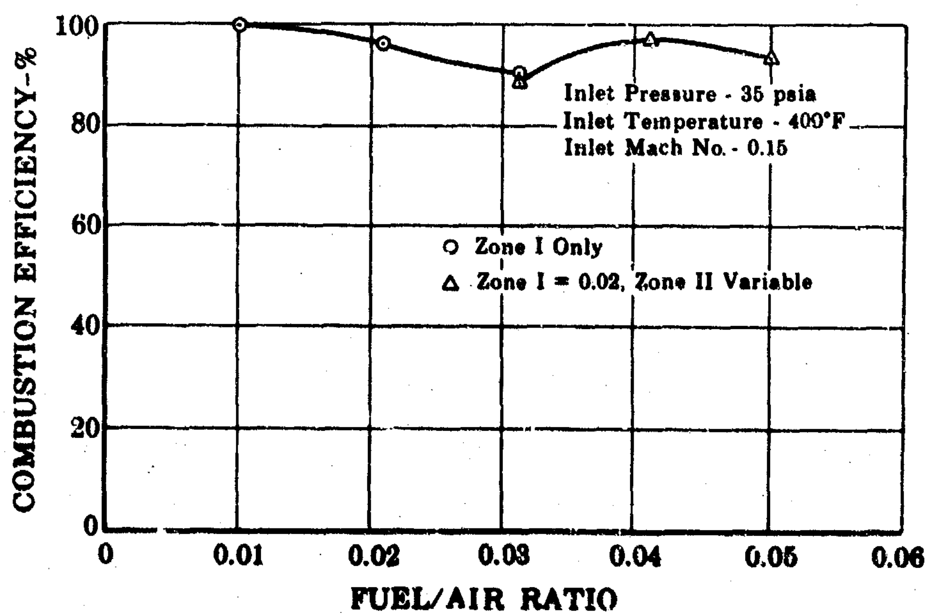

Figure 87. Model J6 Duct Heater Performance FD 16642
EII

H Model Duct Heater

Analysis of previous test results indicated that the cause of poor low pressure performance was quenching of the precombusted mixtures in the aft portion of the combustor before combustion could be accomplished at conditions where reaction rates were low (low inlet temperature and pressure). To alleviate this condition the Model H heater was designed to introduce Zone II fuel along with the air through the rear scoops. This feature can be noted in the photograph of the Model H combustor in figure 88. The operating range increased considerably over the K13 (see table 11) with some degradation in high pressure combustion efficiency as can be noted in figure 89.

L Model Duct Heater

The Model L combustor (figure 90) continued the concept of early introduction of Zone II fuel. The difference between the L and the H Models was the larger dome height and larger primary zone of the combustor. The Zone II fuel was introduced in approximately the same manner as it had been in the Model H. Increasing the height of this dome did not have the beneficial effect on the L Model as it had on previous combustors. The operating range and combustion efficiency (figure 91) did not quite come up to the level of the Model H7. Further testing of the L heater is being conducted as part of Contract NAS3-7907 with the NASA, Lewis Laboratory and will be reported in subsequent SST Monthly Progress Reports.

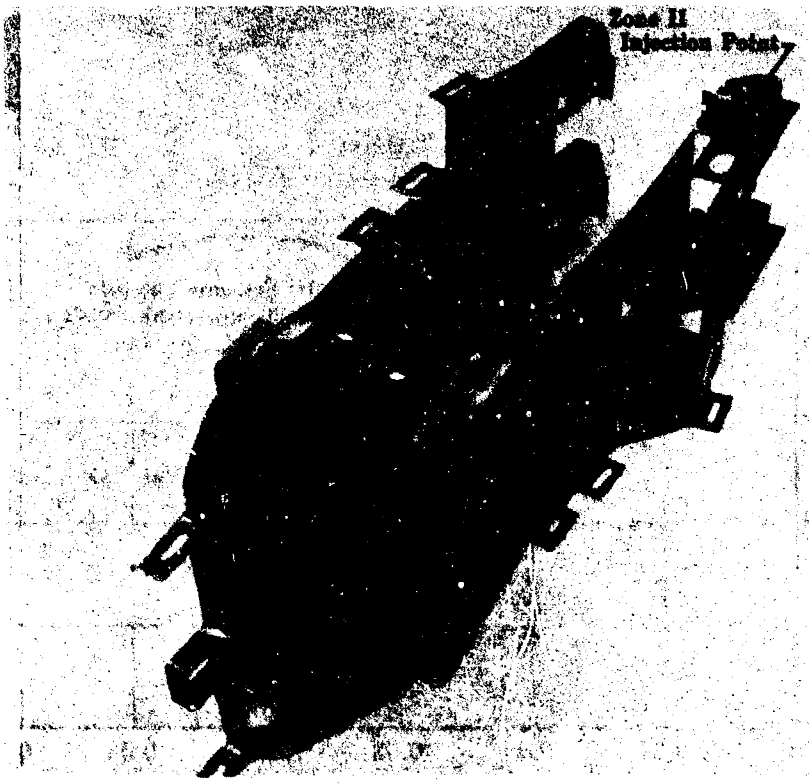

Figure 88. Model H Duct Heater Combustor FD 16655

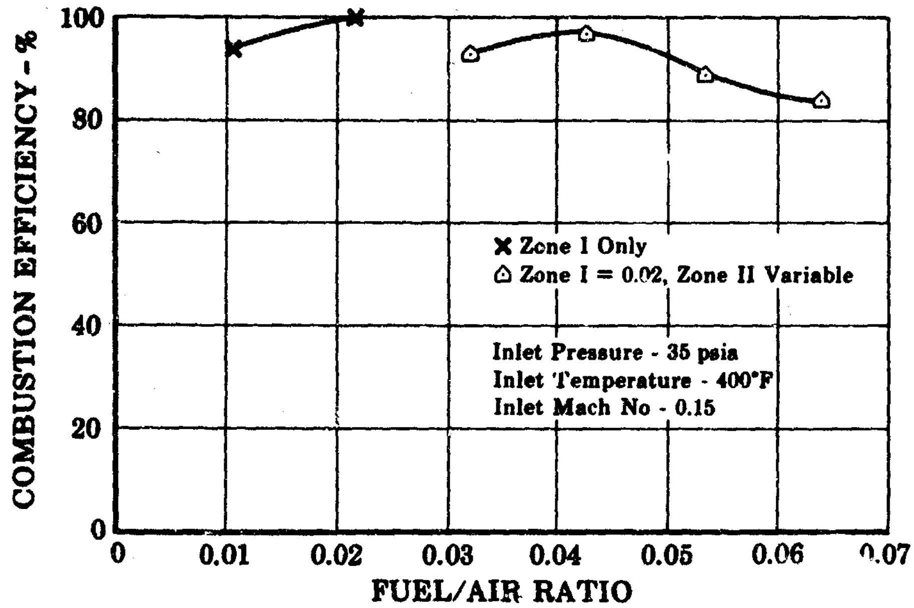

Figure 89. Model H7 Duct Heater Performance FD 16643 EII

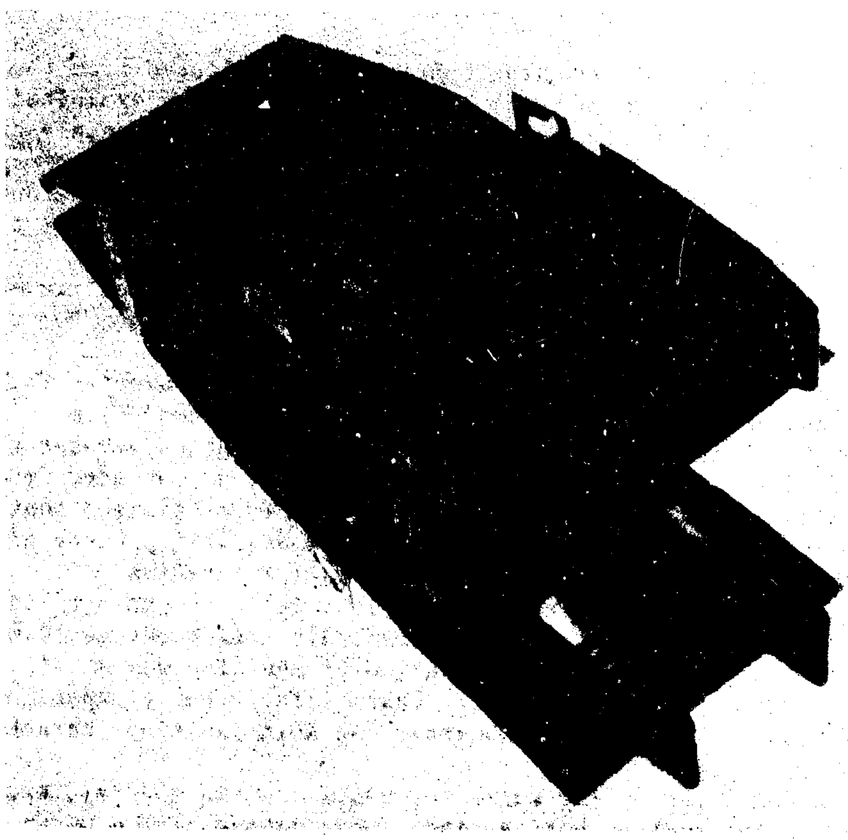

Figure 90. Model L Combustor FE 61507 EII

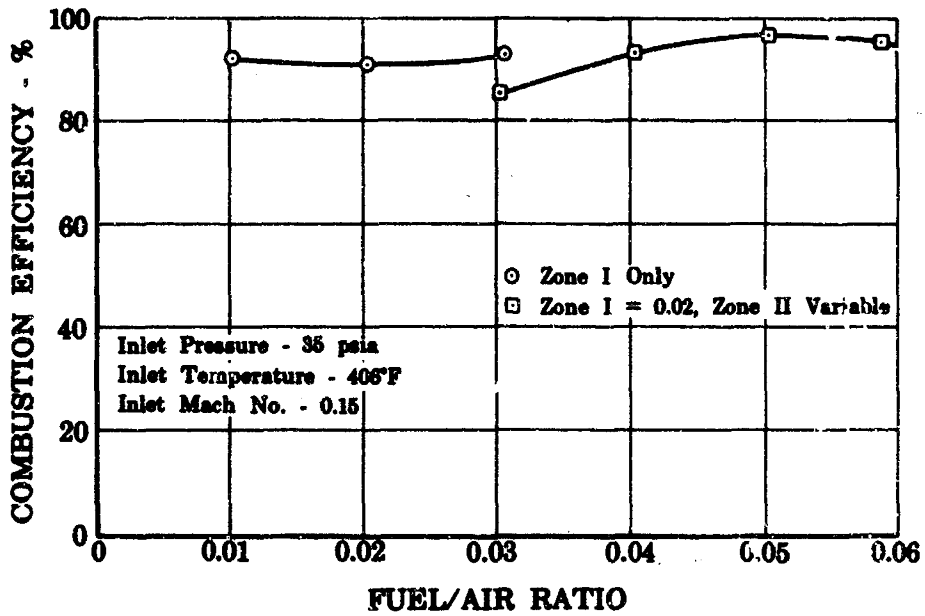

Figure 91. Model L12 Duct Heater Performance FD 16644
EII

c. Conclusions of Phase II-C Testing

1. The duct heater combustor configuration selected from the full-scale sector rig tests for the JTF17A-20 engine exhibited excellent performance characteristics in the full-scale annular rig.
2. The total pressure loss in the diffuser section of the augmentor was lower than predicted and was the primary reason for the low cold pressure loss of the augmentor system.
3. The results from the 7 x 11-inch sector duct heater rig and the 0.6-scale duct diffuser rig agreed well with those from the full-scale annular duct heater rig.
4. The combustion efficiency of the augmentor is greater than 95% for the expected cruise points and for SLTO condition up to F/A= 0.04. Combustion efficiency at fuel/air ratios greater than 0.04 range were between 85 and 95%. It was concluded from the sector rig test (see figure 71 previously mentioned) that better fuel coverage of the combustor bypass air will produce high combustion efficiency at the high fuel/air ratios.
5. The combustor demonstrated excellent ignition characteristics over all conditions tested at fuel/air ratios between 0.001 and 0.004. The pressure perturbation of ignition was small and would not cause fan stall or inlet instability. Early experimental engine testing has corroborated the soft ignition characteristics of the duct heater.
6. The condition of the augmentor parts was, in general, excellent after 45 hours of hot testing. Some damage of the outer liners was encountered in areas of stress concentration. Design changes have been incorporated to eliminate areas of stress concentration and to improve the sound-absorbing characteristics of the liners.

7. The duct heater results have demonstrated that the component can be developed to operate on the JTF17 engine over the required operating envelope with performance equal to or exceeding the goals to meet engine specification thrust and TSFC and with durability required for a long-life commercial aircraft engine.

d. Phase III Augmentor Development Test Program Objectives

The general objective of the Phase III augmentor development program is to provide a level of augmentor performance that will allow the JTF17 engine to meet or exceed the thrust and TSFC objectives and will allow long life engine operation. The specific objectives of the augmentor development plan are:

1. Develop combustor efficiency and pressure loss characteristics needed to meet engine performance goals.
2. Provide duct heater operation over required operating envelope.
3. Achieve ignition that is sufficiently "soft" not to upset engine inlet or fan operation or cause unacceptable discontinuities in engine thrust.
4. Establish acceptable levels of metal temperature, pressure oscillation and vibration to achieve long life augmentor operation.
5. Conduct tests that will insure that the augmentor will achieve performance and endurance levels that will allow the JTF17 engine to successfully complete FTS and certification tests.

e. Description of Augmentor Component Rigs for Phase III

Most of the rigs and facilities that will be used in Phase III are in existance and have been successfully used in Phase II-C. Augmentor component rigs planned for Phase III are:

0.62-Scale Diffuser Rig
Water Tunnel
7 x 11-inch Duct Heater Rig
60-Degree Sector Duct Heater Rig
Annular Duct Heater Rig

(1) Duct Diffuser Rig

The 0.62-scale duct diffuser rig that was used in Phase II-C testing will be modified to represent the wall contouring of the prototype engine design to be used in Phase III. The primary difference between the initial experimental engine duct diffuser and that of the prototype engine is the addition of a flow splitter and absorbent walls to aid fan and noise suppression. The schematic drawing of the diffuser rig and instrumentation location was previously shown in figure 63.

The rig will be tested in either C-1 or C-2 stands of the High Mach Turbine Laboratory. The facilities, which are essentially identical, provide up to 100 lb/sec exhaustor capability which is considerably more than required to simulate the entire range of Mach numbers present in the JTF17 duct diffuser. A photograph of the diffuser rig installed in C-1 stand is shown in figure 92.

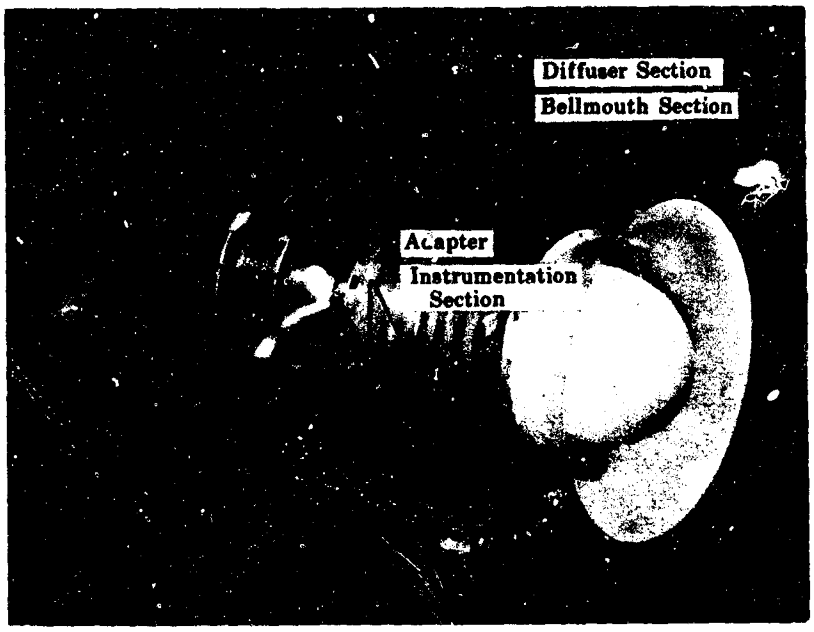

Figure 92. 0.6-Scale Duct Diffuser Rig FD 16637 EII

The instrumentation used in the diffuser test program consists only of pressure measuring devices. To measure total pressure in the main stream, traversable Kiel probes will be used. Total pressure in the boundary layer will be measured by an array of impact tubes at different immersions connected to a fixed rake. Static pressure will be measured at the walls with flush taps and in the stream by disk or "banjo" and wedge probes. These probes have one total port and a static port on each side of the disk or wedge. The probe must be rotated (yawed) until the pressure from each side port are equal; at this point the side port readings will be equal to true steam static pressure. All pressures will be read on "U" tube manometers.

(2) Water Tunnel Rig

The water tunnel, which is now being built at FRDC will provide three-dimensional visual observations of the flow in the augmentor. This rig will provide visualization of gross mixing and flow patterns in the combustor. A schematic of the water tunnel is shown in figure 93. A 12.5-inch diameter propeller, driven by an electric motor will be used to flow a maximum of 5380 gallons per minute through a 1-foot high by 3-feet wide and 3-feet long test section.

Air bubbles, dye, aluminum powder, or polystyrene spheres will be used as tracers. Dye may be used when the velocity and turbulence levels are low. However, high velocities cause a dye dispersion rate too rapid for analysis. Air bubbles have a more substantial density variation than water and may cause significant error in rotating flow. United Aircraft Corporation of Canada has used aluminum powder with good success since aluminum possesses the advantage of remaining as separate particles of sufficiently small size so as to follow the true lines of

flow. Aluminum also has good reflecting properties and therefore is easily visible when illuminated. Another possible tracer is polystyrene beads of 0.5 mm diameter and has the advantage that the specific gravity of the polystyrene is very close to that of water.

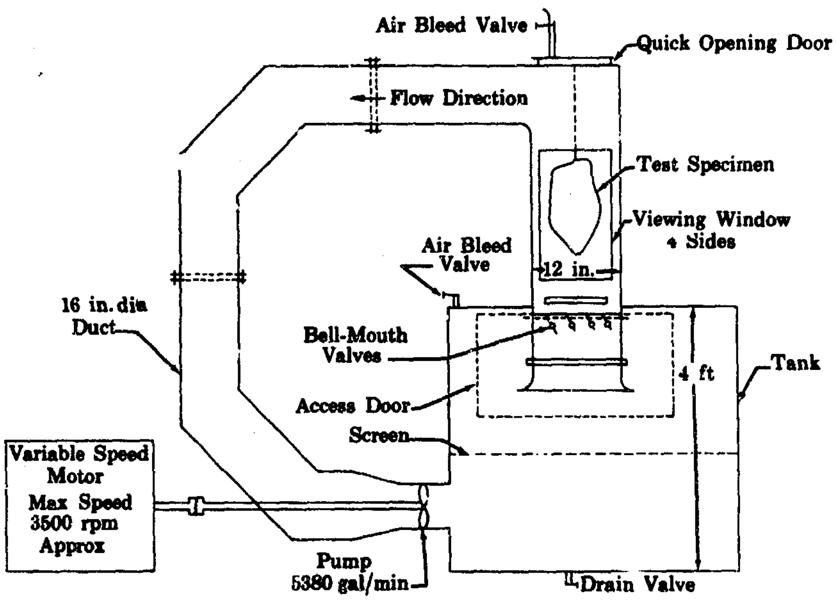

Figure 93. Water Tunnel Schematic FD 16645 EII

Lighting to view the test results and for photographing the flow through the test specimen will be provided by a mercury vapor lamp shining through a 1/16 to 1/8-inch wide slit, extending the length of the test section window perpendicular to the field of view. The flat beam of light permits investigation of the flow pattern in a three-dimensional field of view without obstructing the surrounding flow. The mercury vapor lamp, with a filter, could be used as a source of ultra-violet light through the model to illuminate polystyrene tracers with luminescent material. The test specimens will be made of clear plastic such as "plexiglass".

(3) 7 x 11-inch Sector Rig

The two-dimensional rig which is 11 inches high by 7 inches wide is capable of testing a full-scale sector of the JTF17 duct heater. The rig was used in Phase II and is shown schematically in figure 79 previously mentioned. No rig modification will be required in Phase III to accomodate the prototype engine duct heater.

The test facility, (B-2) utilizes J-75 engine compressor bleed as an air supply and the engine exhaust gas as the driving energy for a two-stage ejector. A schematic of the facility is shown in figure 94. The facility has been improved by adding a heat exchanger between the engine and the rig. The exchanger will allow independent control of rig inlet pressure and temperature and rig exhaust pressure. The facility will have the capability of testing the 7 x 11-inch duct heater rig over the entire duct heater operating envelope. Figure 95 shows the 7 x 11-inch duct heater rig installed in B-2 stand.

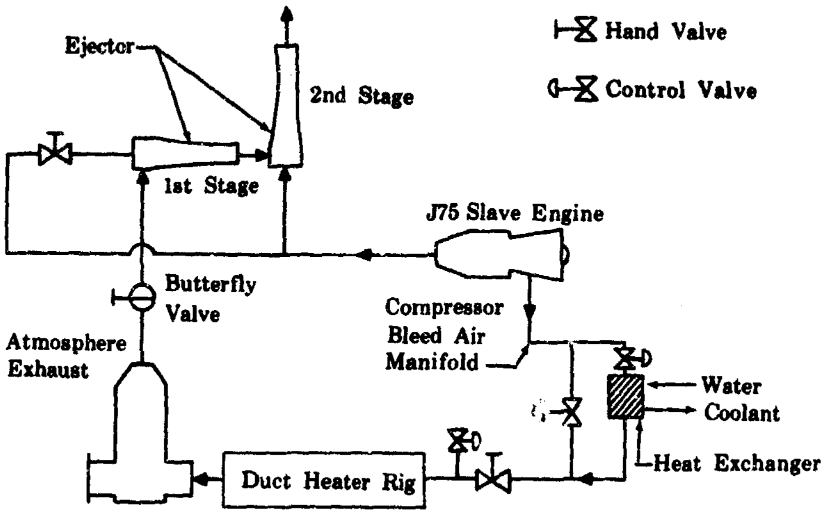

Figure 94. Duct Heater Rig Test Stand Schematic FD 15609A
EII

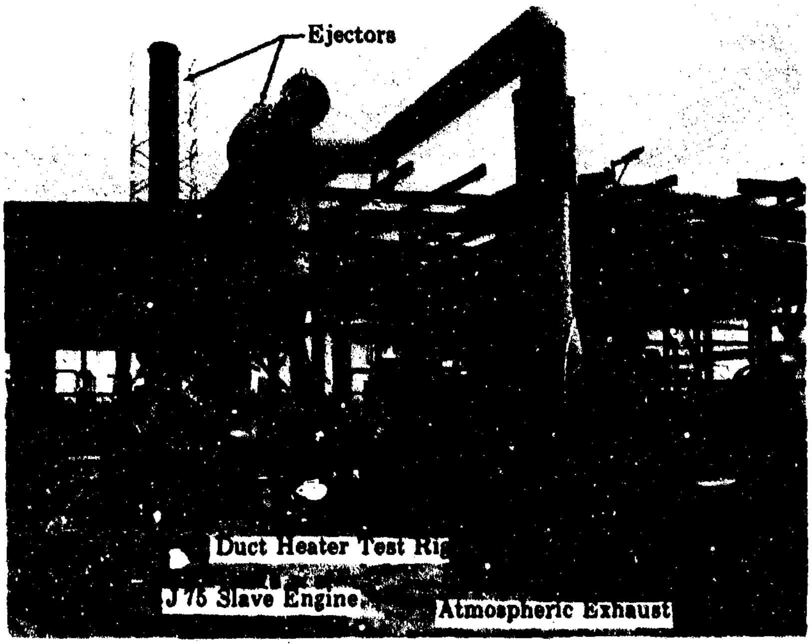

Figure 95. Duct Heater Sector Rig Installed in B-2 Test Stand FD 15610
EII

The importance of duct heater combustion efficiency to the performance of an augmented turbofan engine requires that the measurement of combustion efficiency be very accurate. In the past, combustion efficiency has been determined by measuring the temperature rise and comparing it to the theoretical temperature rise obtained from the metered fuel/air ratio and the chemical composition of the fuel (Hydrogen/Carbon ratio):

$$\eta = \frac{\Delta T_{act}}{\Delta T_{ideal}}$$

Errors in the efficiency number arise from the errors in measuring temperature, fuel flow, and airflow. In carefully conducted tests, combustion efficiency may be measured to within $\pm$ 2.5%. A far better method of determining efficiency is to measure the inefficiency directly by removing a sample from the stream and measuring the amount of the unburned combustible products that contribute to the inefficiency (H_2, CO and hydrocarbons). Conventional gas analysis techniques (chromatography, infra-red analysis, etc.) in the past have required excessively long sampling time and have been too cumbersome to be a useful combustion development tool.

Pratt & Whitney Aircraft has devised an "inefficiency meter" that can determine the combustion efficiency and fuel/air ratio of a sample in less than 30 seconds. This device will make possible the measurement of combustion efficiency, and fuel/air ratio at numberous points within the combustor as conveniently as temperature is now measured. This meter will measure combustion efficiency to within less than $\pm$ 0.5%. The availability of accurate maps of fuel/air ratio and combustion efficiency at the combustor exit plane or within the combustor will naturally reduce the development cost of the combustion system.

The P&WA inefficiency meter consists of six basic components (see figure 96).

1. Combustion product sample inlet heater
2. Flow control
3. Temperature rise meter
4. Fuel/air meter (infra-red analyzer)
5. Electronic controls
6. Remote control panel

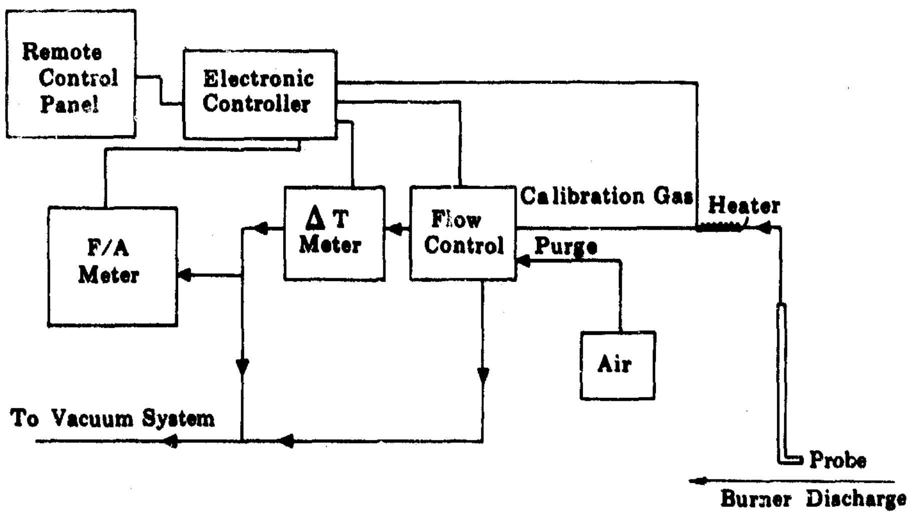

Figure 96. Inefficiency Meter Layout FD 16646 EII

The gas sample is isokinetically removed from the stream, cooled to 400°F and piped at a constant temperature to the flow controller. The sample then flows from the controller to the ΔT meter, which consists of a preheater and a catalytic reaction cell. The sample is rapidly heated

to 1220°F, the temperature just below the point at which rapid reaction will take place. The temperature of the heater is exactly maintained by the use of a large container of molten aluminum as a heat source. In the catalytic cell, the reaction is allowed to take place, and the temperature rise due to reaction is measured. The catalyzed sample then enters an infra-red analyzer to determine the CO_2 (fuel/air ratio).

A test of the accuracy and of the instrument is now being made by measuring the combustible products and fuel/air ratio of a specially-prepared calibration sample. Early results of the tests indicate that the desired measurement accuracy can be achieved.

All duct heater rigs will use the inefficiency meter as the primary measurement of chemical combustion efficiency. The thrust-equivalent combustion efficiency will be calculated by taking into account the temperature and pressure profile as explained in Volume III, Report A, Section IIID. The thrust "weighted" combustion efficiency will be compared to the thrust efficiency obtained from the choked nozzle where possible.

(4) 60-Degree Sector Duct Heater Rig

While the 7 x 11-inch sector rig has many advantages due to its small size and relatively low air flow requirements, it lacks sufficient width to be a complete development tool. The small width is particularly limited in determining the effects of fuel coverage or trying to measure temperature distribution circumferentially. For this reason a new sector rig, considerably wider than the 7 x 11-inch rig will be built.

The rig will consist of a 60-degree full scale segment of the annular burner and will replace the 7 x 11-inch sector rig. By selecting a larger segment, distortion effects due to the side walls are minimized, and interaction of the swirlers and liner cooling flow requirements may be studied. The 60-degree sector rig will provide a test section that will in section duplicate the full-scale annular augmentor from the diffuser to the nozzle.

The 60-degree sector rig will consist of the following sections as shown in figure 97.

1. Venturi
2. Adapter (Plenum)
3. Diffuser
4. Combustor
5. Tailpipe
6. Nozzle.

A venturi, to be utilized for airflow measurement, is the inlet to the rig.

An adapter section, consisting of a plenum and provisions for adapting from the round venturi to the 60-degree segment, will be provided to reduce inlet velocities so as to provide a controlled inlet profile to the diffuser.

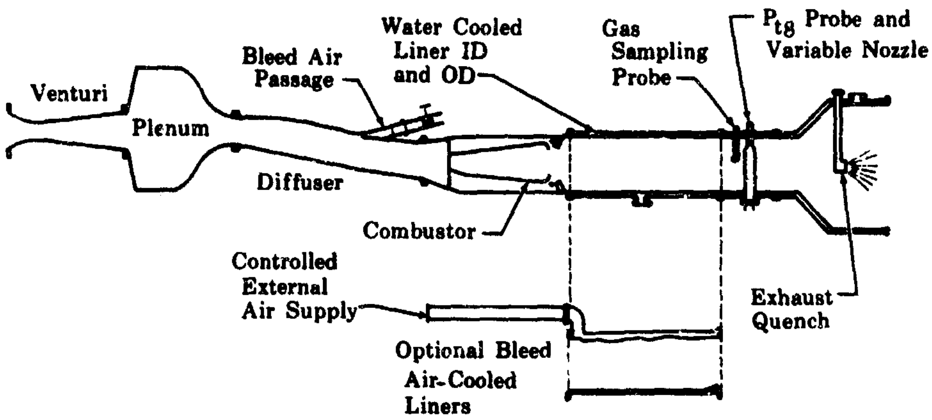

Figure 97. Duct Heater Rig

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The diffuser will be aerodynamically the same as the engine. Provisions will be made to independently control and measure inner liner cooling air. This will either be dumped overboard when running with a water cooled tailpipe or reinserted into an uncooled tailpipe for liner cooling.

The test section will be mounted in the combustor section from two struts. These struts will be aerodynamically similar to the engine configuration. The burner support section will be uncooled, with the end walls lined with graphite to provide a heatshield to reduce quenching of the combustion process by the cooler walls.

Two tailpipes will be used during the test program: a fully water cooled tailpipe and an air cooled tailpipe. The water cooled tailpipe will be used in tests where liner cooling performance is not an objective. Heat rejection to the water jacket will be measured and efficiencies corrected accordingly. The combustion inefficiency measured by gas analysis will not require this correction. The air tailpipe will use engine liners where cooling flow and heat transfer rates will be evaluated.

A variable area nozzle will have the capability of setting a known area that can be varied during the test. The area variation will allow operation of the combustor from fuel/air ratios of 0.001 to 0.067 and reference Mach numbers (Mach number in duct without combustor) to 0.2.

The 60-degree sector rig will be operated in C-1 or C-2 test stand. The test stand can operate the rig over important regions of the flight envelope. It is capable of supplying nonvitiated air to 800°F at 100 lb/sec. Exhausters can provide pressures down to 5 inches of mercury at the flow rates required. It is anticipated that a maximum of 66 lb/sec airflow at 40 psia will be required at the rig.

Two separate fuel systems will be provided for Zone I and II operation. Constant displacement pumps will be used. The Zone II system will have the capability of metering flow to the inner and outer fuel injectors

separately. As in the annular rig fuel system, the starting fuel flow will be set in a bypass system and a three-way valve actuated for flow to the rig. Vernier valves and dual-range flowmeters will permit fine control of the system and regulation of flows to fuel/air ratios to within 0.001 of desired setting.

Ignition will be accomplished by a spark igniter. Ultra-violet sensing photoelectric cells will be mounted into the combustor section side walls to monitor ignition. If the duct heater flame goes out, the photoelectric cells will immediately shut off the fuel supply valve to the combustor.

Instrumentation will be provided to measure operating conditions determine losses through the duct heater, and prepare air and fuel flow rates. Chemical efficiencies will be measured by the P&WA inefficiency meter. Thrust-equivalent efficiency calculations will utilize the nozzle area and pressure ratio across the nozzle. The data will be recorded on a 90 channel recording system. A data point will normally take 30 seconds.

(5) Annular Duct Heater Rig

The full-scale annular rig which was used in Phase II-C exactly simulates the engine fan flow path from the point of fan discharge to the inlet of the exhaust nozzle. A schematic of this rig and instrumentation location was previously shown in figure 68. The parameters measured were:

1. Total duct air flow rate
2. Liner cooling flow rates
3. Duct total and static pressures
4. Duct inlet and outlet temperatures
5. Duct static pressure oscillation
6. Duct vibration (acceleration and displacement)

The primary purpose of the instrumentation is to measure combustion efficiency, pressure loss and cooling liner flow. During Phase II-C, efficiencies were calculated from the measurements of airflow through a standard ASME 40-inch orifice, fuel flow through turbine flowmeters, and exit temperatures and pressures from eight traversing probes. Each of these burner exit temperature probes incorporated aspirated, shielded, irridium-irridium-rhodium, dual-element thermocouples and total pressure sensing elements. Gas sampling probes will be used in conjunction with the exit temperature probes during Phase III testing. The temperature and gas sampling probes will be mounted on a rake that radially traverses the exit area in 10 equal-area steps. The rake will be automatically stopped at each position, stabilized for a preset time period, provide the automatic data recording system with a record signal, and then proceed to the next point. All data will be recorded automatically, stored on magnetic tape and transmitted to the data recording center. An IBM 1420 computer will be used to compute combustion efficiency, rig inlet Mach number, air flow, exit temperature and other important parameters.

These results will then be transmitted via teletype back to the test stand within minutes after the point has been recorded. In addition to automatically recorded data, manometers, gages, flow connectors and temperature readouts will be provided in the control room to monitor rig operation.

Pressure oscillations and vibrations will be monitored with high-frequency-response crystal pressure transducers and accelerometers respectively.

The annular duct heater rig can be operated over all duct heater operating conditions of interest as indicated in figure 98. The facilities that will be used (C-4 or C-5) presently have a maximum air capacity in excess of duct heater rig requirements. The only conditions in the duct heater operating envelope that cannot be consistently provided are temperatures lower than 240°F at pressures above 14 psia due to lack of compressor discharge air coolers. This range of conditions is shown as the shaded region in figure 98 and is not considered to be of major importance in duct heater development program.

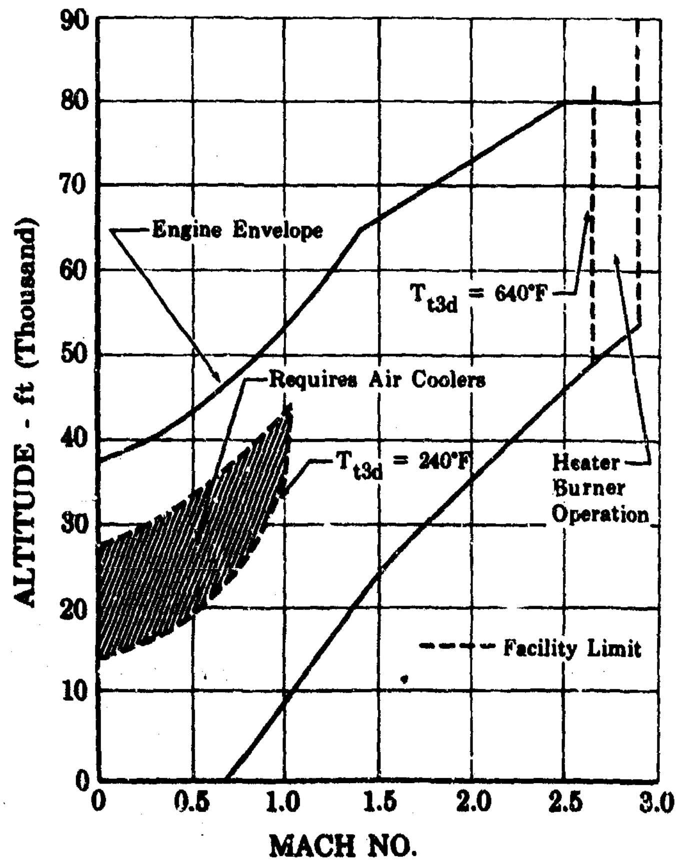

Figure 98. Annular Duct Heater Rig Facility Operating Limit

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f. Augmentor Test Program

The test program that is to be conducted on the rigs described in the previous section is as follows:

(1) Diffuser Rig

The 0.6-scale annular diffuser rig will be used to evaluate the JTF17 diffuser to determine its performance and sensitivity to inlet total pressure profile. Since this has been done for the early experimental engine configuration, emphasis will be placed on determining the effect of sound suppression devices on diffuser performance.

The test will be conducted in a manner described in Paragraph 5a above. Diffuser total pressure loss, static pressure recovery and Mach number profile will be determined from the data and will be presented as shown in figures 64 and 65 previously mentioned. Approximately 150 hours of diffuser testing will be required.

(2) Water Tunnel Rigs

The purpose of tests in the water tunnel rig is to visually observe flow phenomena in combustors. The observations, when combined with data from combustion rigs, can aid in determining "why" certain configurations perform as they do. The testing in the water tunnel would be conducted in conjunction with a combustion rig, in this case the 7 x 11 inch sector rig, until correlation between the flow patterns and combustor operations could be established. An example of the interplay between the water tunnel and sector duct heater rig tests would be as follows: a combustor scoop configuration is tested in water tunnel and is observed to have very strong recirculation near the dome of the combustor; when the same configuration is tested in the sector rig, the lean blowout is found to be at a higher fuel/air ratio than previous configurations; the analysis of this information would be, that while recirculation is necessary for combustion, the scoop configuration in question provided too much air in the primary zone for stable low fuel-air ratio operation.

Approximately 30 configurations will be tested in the water tunnel rig over a period of approximately 300 hours of rig time.

(3) 7 x 11-inch Duct Heater Rig

The 7 x 11-inch rig will be used in the early stages of Phase III (in conjunction with the water tunnel rig) to study radial mixing and its effect on operating range and combustion efficiency.

The operating range will be evaluated on the basis of the range of fuel-air ratio that the configuration will support combustion at severe inlet conditions. The combustion effeciency will be determined at these conditions as well as conditions of greater interest (i.e. simulated SLTO, cruise and transonic acceleration). The data will be analyzed and presented in the manner described in Paragraph 5a above.

(4) 60-Degree Sector Duct Heater Rig

The major portion of the augmentor development testing will be performed with the 60-degree sector rig. All aspects of augmentor operation will be evaluated with this rig and will include the following types of tests:

1. Performance Calibration - This test sequence is a combination of tests that will be conducted on each configuration to determine the duct heater ignition capability, operating range, combustion efficiency and total pressure loss at prescribed conditions. The performance parameter would be measured at engine guarantee points. Burner operation would be assessed at off design conditions (i.e. $P_{T3D} < 10$ psia) to determine the margin in operating range. Ignition would be attempted at each performance point and at the low pressure operating points.

2. Ignition Tests - This series of tests will be conducted on configurations that appear suitable for engine testing. In these tests, the entire range of ignitability would be defined in terms of inlet pressure and temperature and fuel/air ratio. These tests would normally be performed with ambient temperature fuel. Any configuration selected for the engine Parts List will have the ignition envelope defined using cold fuel.

3. Operating Range Tests - These tests would be performed on selected configurations to define the range where combustion could be maintained within the capabilities of the facility. The results would be expressed in terms of the fuel-air ratio range and inlet temperature and pressure.

4. Special Durability Tests - Parts endurance, as such, will not be evaluated on rigs. Tests will, however, be performed to evaluate those parameters that affect endurance such as metal temperatures, coolant temperature and flow rates, etc. . .

Approximately 175 configurations will be evaluated during Phase III requiring approximately 1750 rig hours.

(5) Full-Annular Duct Heater Rig

The main purpose of the full-annular rig testing is to verify the results of the 60-degree sector rig and to ensure that the configuration is suitable for engine testing. The important feature of the annular rig is that it enables the testing of actual engine hardware throughout the engine operating envelope as well as off-design conditions. The types of testing that will be accomplished using the annular duct heater rig are:

1. Fuel Distribution Tests - The establishment of fuel staging (relationship between Zone I and II flow rates) will be determined from annular rig tests by varying flow splits at important operating points.

2. Ignition and Operating Range Verification Tests - The operating range and ignition characteristics of duct heater configurations will be verified before placing the configuration on the engine Parts List. The test efforts will be spent on defining the operating range and ignition margin by testing at off-design conditions. The ignition tests will be performed using ambient or cold fuel depending on the phase of the development program.

3. Performance Verification Test - The performance of configurations selected on the basis of the 60-degree sector rig testing will be verified in the annular duct heater rig. Testing will be normally conducted at the engine guarantee points. Configurations being considered for FTS or certification listing would be tested over the full range of inlet conditions.

4. Special Durability Tests - Short time endurance tests, tests to determine metal temperature, temperature and cooling flow rates will be conducted in the annular rig.

Engine testing will primarily be used to evaluate the augmentor endurance.

(6) Summary of Development Test Plan

The sequence of events that will occur in the Phase III duct heater component development program are:

The prototype JTF17 duct heater will be fabricated and evaluated in the diffuser rig, the 7 x 11-inch duct heater rig and the water tunnel rig. Basic mixing studies will be conducted on water tunnel and the sector rig. The 7 x 11-inch rig will be retired when the 60-degree sector rig becomes available (see figure 99). In the meantime a complete assessment of the prototype augmentor performance to define problem areas and to perform tests necessary to establish correlation between the annular and 60-degree sector rigs will be conducted. Once rig correlation has been established, new configurations will be designed and evaluated in the 60-degree sector rig. Promising configurations will then be made for the annular rig for futher evaluation. Configurations that prove promising in the annular rig tests will be evaluated in the engines.

A summary of rig effort is presented in table 12.

Table 12. Summary Estimated Total Rig Hours
End of Phase III

1.	Annular Rig	690 Hours
2.	60-Degree Sector Rig	1700 Hours
3.	7 x 11-inch Sector Rig	480 Hours
4.	Diffuser Rig	150 Hours
5.	Water Tunnel	260 Hours

g. Augmentor Test Schedules

The schedule for the JTF17 augmentor development calls for an estimated 3800 hours of rig testing, starting in February 1967 and continuing to the end of Phase III in December 1969. The time phase relationship for the augmentor development program is shown in figure 99. The 0.6-scale diffuser rig, the 7 x 11-inch sector duct heater rig will be used in the early phase of the program and will be phased out when the 60-degree sector rig is successfully operated in August 1967. Testing in the annular duct heater rig and the 60-degree segment will be initiated during July 1967 or sooner and continue to the end of Phase III. The accumulation of rig testing with respect to time for each rig is shown in figures 100 through 104.

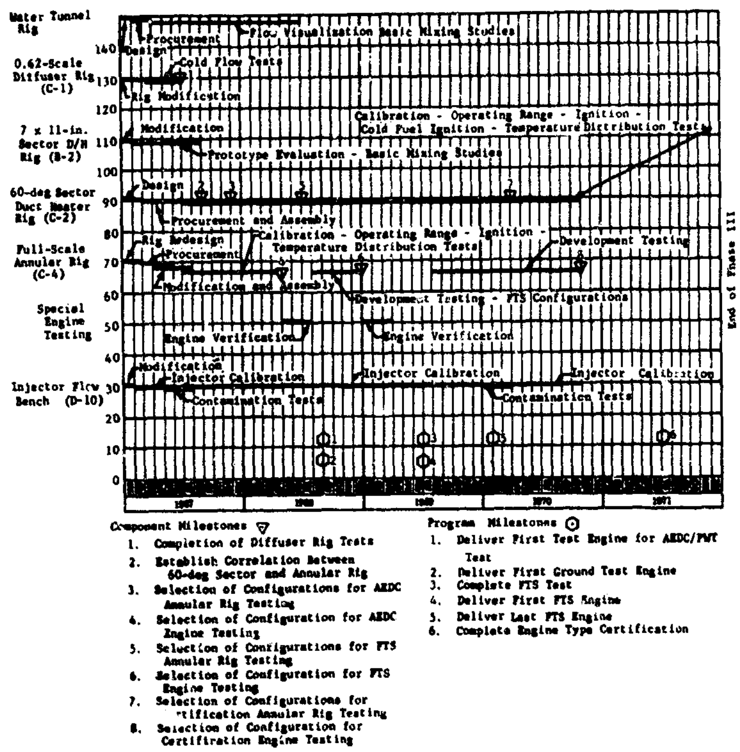

Figure 99. Duct Heater Development Plan

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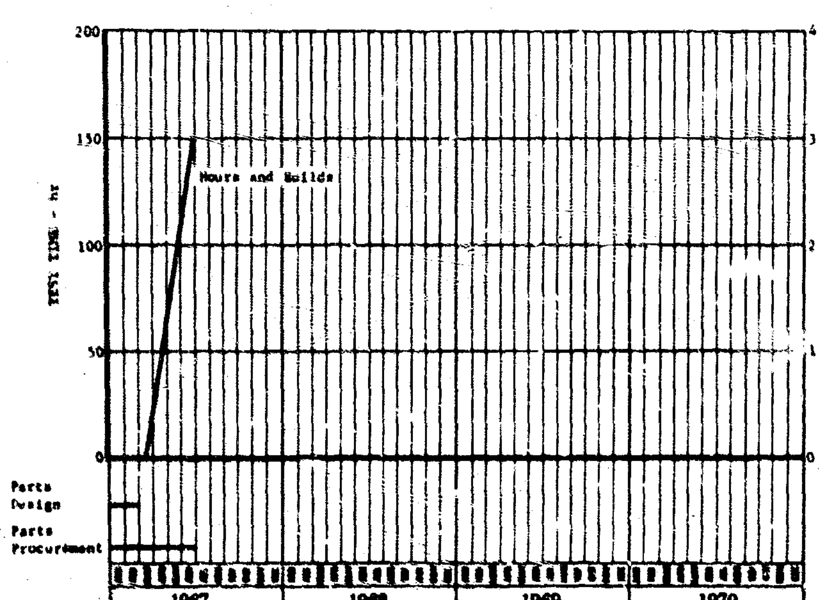

Figure 100. 0.62-Scale Diffuser Rig Schedule

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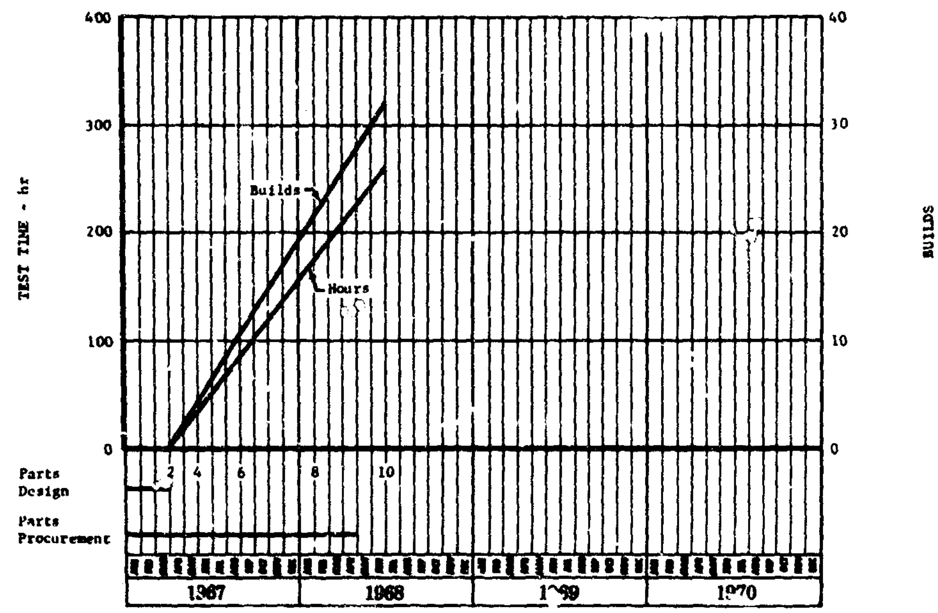

Figure 101. Water Tunnel Rig Schedule

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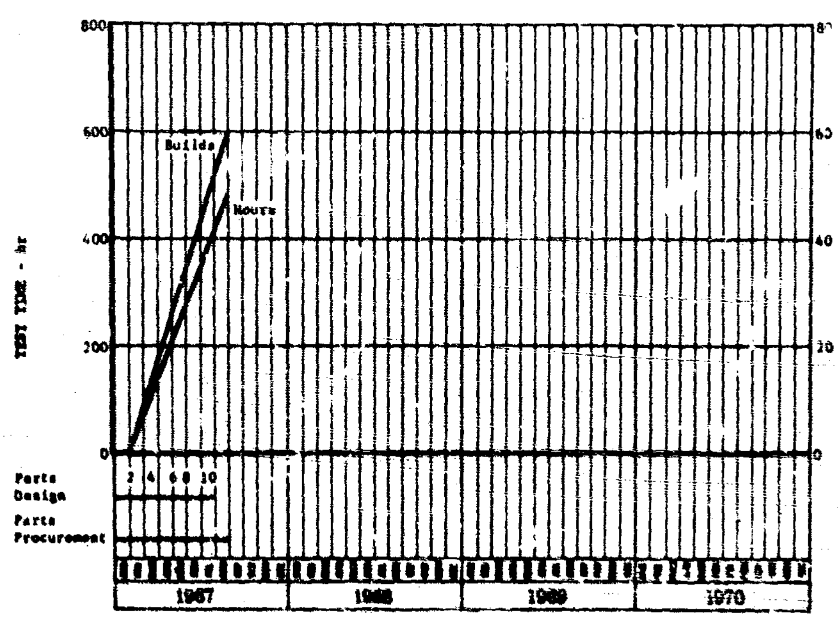

Figure 102. Duct Heater Rig Schedule, 7 x 11-in. Sector

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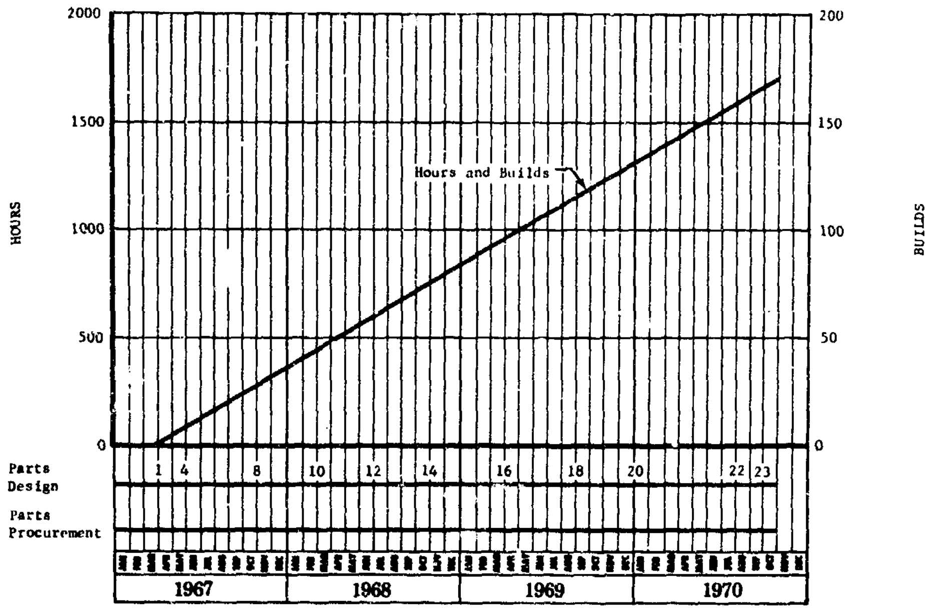

Figure 103. 60-degree Duct Heater Rig Schedule FD 16653 EII

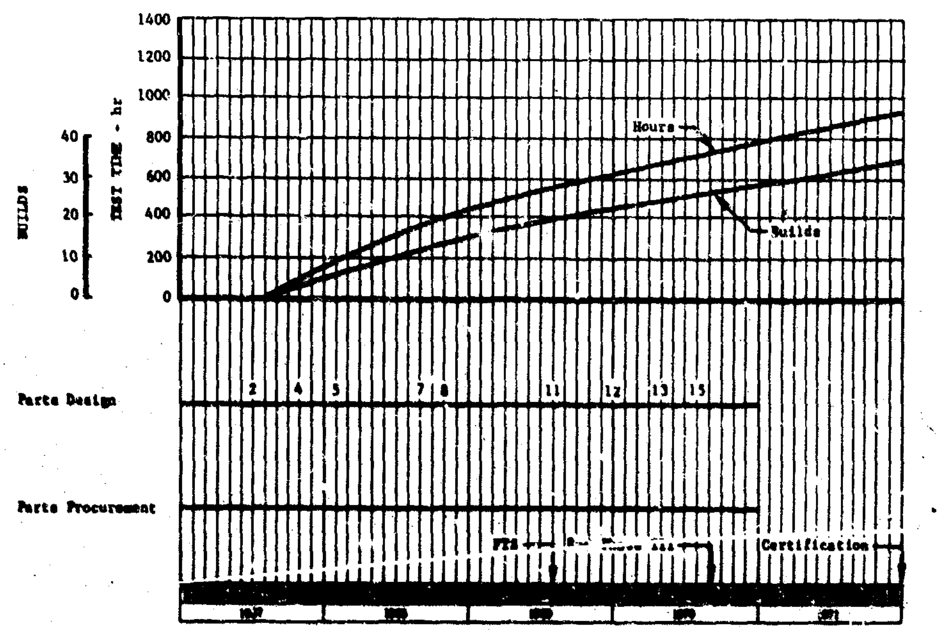

Figure 104. Full-Scale Annular Duct Heater Rig FD 17633 EII

6. Exhaust System

a. Introduction

(1) Description of JTF17 Exhaust Nozzle System

The JTF17 exhaust nozzle consists of a variable area duct nozzle, a fixed area primary nozzle and a blow-in door reverser-suppressor. The variable area duct nozzle is used to control duct air flow and, with the primary engine nozzle, provides the convergent portion of the exhaust nozzle system. The blow-in door reverser-suppressor forms the divergent portion of the exhaust nozzle as well as providing for thrust reversal and noise reduction.

The purpose of the JTF17 exhaust system is to (1) control the expansion of the exhaust gases to achieve maximum performance levels at all operating conditions, (2) provide an efficient method of reversing the exhaust gases to provide a high level of reverse thrust and (3) effectively suppress engine exhaust noise.

Pratt & Whitney Aircraft has chosen the clamshell blow-in door ejector reverser-suppressor to fulfill the requirements of the JTF17 engine in its three basic modes of operation as a result of a comprehensive study of several candidate exhaust systems. The nozzle employs both physical and aerodynamic means to reduce performance losses associated with non-cruise condition operational modes.

During low speed operation (figure 105a) the tertiary-air doors are open and external (tertiary) air is drawn into the nozzle along with any available secondary airflow to aerodynamically reduce overexpansion losses. The clamshells are rotated to the proper angle to permit admission of the tertiary air. The pressure-actuated trailing edge flaps are closed, due to pressure loading, and physically reduce overexpansion losses by reducing the exit area. At high subsonic Mach number, the closed trailing edge flaps produce external pressure drag, and so a compromise must be reached between the quantity of tertiary air induced and the minimum exit setting of the trailing edge flaps.

As the aircraft continues to accelerate to high transonic flight Mach numbers, the tertiary doors will close because of increased internal pressures. The trailing edge flaps will continue to reduce overexpansion losses by providing small exit areas. At higher flight Mach numbers, the trailing edge flaps move outward to the cruise configuration as shown in figure 105b. A small quantity of secondary airflow is required whenever the tertiary doors are closed to control the expansion of the engine gas stream and also to cool the ejector surfaces. During reverse operation, the reverse gas is exhausted through the tertiary-air doors at the desired angle (see figure 105c). A more detailed description of the blow-in door reverser-suppressor is given in the design portion of the proposal (Volume III, Report B, Section IIE).

Exhaust system performance has a larger effect on aircraft performance than any other single engine component. A one percent change in nozzle efficiency at cruise condition is equivalent to 5800 lbs payload or 130

statute miles in aircraft range on a typical 4000 statute mile flight. It is therefore necessary to obtain very high exhaust nozzle efficiency while maintaining simplicity of operation and minimizing the weight of the engine.

This section of the proposal will discuss the component development work that is planned for Phase III to provide the required exhaust system performance level and the structural integrity necessary for long life service. Component evaluation will be concentrated in the following areas:

1. Aerodynamic model testing
2. Component endurance and structural testing
3. Engine reverser-suppressor testing

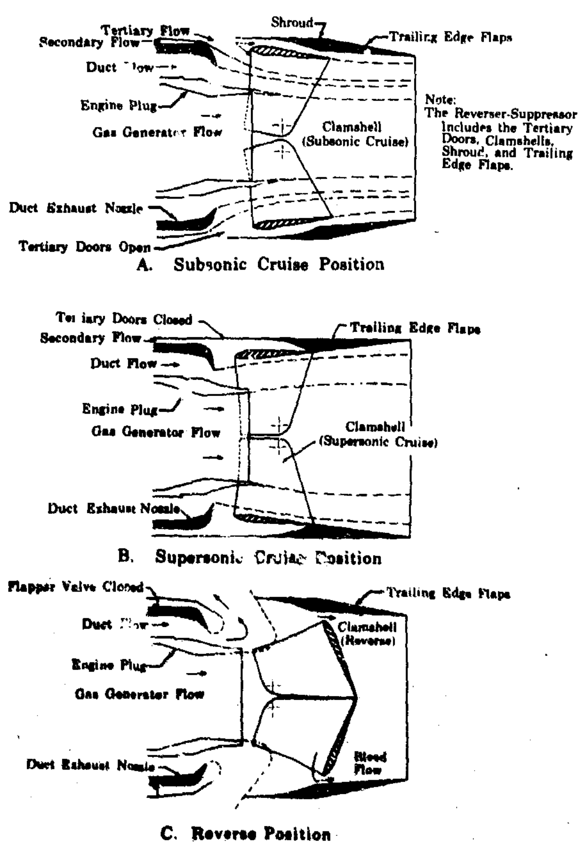

Figure 105. JTF17 Reverser-Suppressor

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(2) Current State-of-the-Art

Pratt & Whitney Aircraft has had extensive experience in the development of blow-in-door ejector exhaust systems. Since the initial conception of the blow-in-door ejector in 1957, many thousands of hours of model testing has been conducted to firmly establish design procedures and performance levels of these exhaust nozzles. The many configurations investigated

include the conventional two-fold blow-in door ejector nozzles and the co-annular flow blow-in-door ejector/reverser system as proposed for the JTF17 supersonic transport engine. Significant advances have been made in achieving the original performance goals for the supersonic transport exhaust system. The thrust reverser studies indicate acceptable levels of reverse coefficients are possible even with severe targeting requirements and with little or no engine airflow suppression.

The reverser-suppressor type of exhaust system was selected for the JTF17 engine because it is a natural evolution from previously successful hardware concepts. The blow-in-door, floating-exit flap ejector has been under intensive development for the past seven years. One version of this type ejector is operating with outstanding success with the J58 engine on the YF12A interceptor aircraft. The high Mach number flight performance obtained with the J58 exhaust system has indicated very good agreement between predicted and actual nozzle performance levels. A similar ejector is now being developed for the TF30 engine for the F-111.

The clamshell thrust reverser feature is quite similar to the Pratt & Whitney Aircraft primary jet reverser used on the JT3D in the DC-8 and reversers on the JT3, JT4, JT3D and JT8D engines on Boeing 707 and 727 airplanes. These engines have accumulated more than 38 million hours of commercial service and have become the reliability standards of the industry.

The continuing technology and design concepts gained from the J58, TF30, JT3D and JT8D applications have been incorporated into the design of the JTF17 reverser-suppressor. This includes such items as the use of titanium for weight reduction, tertiary-air bleed for noise suppression, geometry selection for maximum overall performance and fabrication and assembly techniques for low cost construction and ease of maintenance.

(3) Phase II-C Status

(a) Full-Scale Testing

Two full-scale reverser-suppressor assemblies are being constructed for sea level static testing during Phase II-C. Tests on the first reverser-suppressor are scheduled to begin during September 1966. The results of these tests, while not available for discussion in this proposal, will be available in time to verify overall concept feasibility, and for use in finalizing the prototype JTF17 design in Phase III. These tests will also provide a basis for performance correlation with wind tunnel model test results.

(b) Aerodynamic Model Testing

The Phase II-C reverser-suppressor model test program was directed toward development of the exhaust system to obtain flow geometry consistent with good mechanical design and to verify the performance objectives at critical flight conditions. The performance objectives have been demonstrated with several model configurations. Inasmuch as the exhaust system configuration must be varied with flight condition, consideration must also be given to obtaining the best mechanical design

as well as high performance. The exhaust system development program for Phase II-C has resulted in a sound mechanical design which can meet or exceed the performance goals.

The scale model exhaust systems for the SST were tested in facilities of the United Aircraft Research Laboratories. The facilities used included a static test stand, a continuous-flow interchangeable subsonic-transonic wind tunnel, and a 17-inch by 17-inch transonic-supersonic blow-down wind tunnel. All have a three-flow balance that splits, meters, and throttles three concentric flows.

Tests of 1/20-scale models were conducted to maximize performance by a systematic variation of exhaust system geometry. Variations in the geometry of the tertiary doors, shroud, clamshells, and engine plug configurations were investigated at the following critical flight conditions:

Mach 0.0	Takeoff
Mach 0.9	Cruise
Mach 1.2	Acceleration
Mach 2.7	Cruise
Mach 0.0, 0.6 & 0.9	Reverse

Approximately 1600 hours of wind tunnel test time, directed toward establishing the optimum reverser-suppressor configuration consistent with good mechanical design, lightweight, and high performance, have been completed as of August 1966. Detailed results of these tests are discussed in the performance section of the proposal (Volume III, Report A, Section IIIE). Based on results of these tests, the design of the exhaust system configuration for the JTF17 meets or exceeds the performance goals. Development of this configuration will be continued during Phase II-C and in Phase III.

Tests have also been conducted to establish preliminary installation effects. Approximately 230 hours of testing with a wing-mounted installation on exhaust system performance during subsonic operation has been determined. Initial results presented in Volume III, Report A, Section IIIE indicate little or no effect at the conditions tested, subsonic cruise at Mach 0.6 and 0.9. The installation effects during transonic acceleration will be investigated during Phase III. No installation effects are expected at supersonic cruise conditions for the cylindrical nacelle configuration investigated. However, if other nacelle configurations are required, Pratt & Whitney Aircraft will investigate these configurations in conjunction with the airframe manufacturer.

Test programs and analytical studies have also been conducted to investigate exhaust system trailing edge flap stability, hot flow effects, and advanced exhaust system design concepts. The results of these studies are discussed in the performance section.

b. Component Development Test Program Objectives

The overall objective of the exhaust system component development program is to provide a lightweight structure that is capable of operating 10,000 hours between overhaul with normal maintenance and minor

repairs and provide nozzle efficiencies for sea level take-off, subsonic cruise, transonic acceleration, and Mach 2.7 cruise to meet the performance of the Engine Model Specification. The exhaust system must be maintainable and have well defined service limits.

The supersonic flight mode of exhaust system performance cannot be duplicated on a sea level test stand. Since the only existing altitude test facility capable of duplicating the JTF17 engine exhaust conditions and high altitude Mach numbers is located at AEDC in Tullahoma, Tennessee, only a limited amount of engine endurance testing at altitude conditions can be planned. It is therefore necessary to conduct a comprehensive test program on the smaller components of the exhaust system using laboratory apparatus as well as extensive SLTO engine testing. The objectives of the component development program will include:

1. Aerodynamic Model Testing - To improve aerodynamic performance and noise suppression of configurations that are mechanically simple and can be fabricated within engine weight limits. The performance goals of the JTF17 exhaust system are:

Mach Number	Flight Condition	Nozzle Gross Thrust Coefficient C_{f_p}, with 2% Corrected Secondary Airflow for Forward Flight, (Zero Secondary Airflow for Reverse Operation)
0.0	Take-Off	0.980
0.9	Cruise	0.923
1.2	Acceleration	0.967
2.7	Cruise	0.999
0.0	Reverse	40% of Maximum Non-Augmented Thrust Corresponding to $C_{f_v} = 0.47$

2. Component Endurance Testing - To provide long parts life for economical commercial service. Durability development of the exhaust system will be conducted on experimental JTF17 engines as discussed in Volume III, Report E, Section III.

c. Description of Component Rig Testing

(1) Exhaust Nozzle

The variable area augmentor duct exhaust nozzle is composed of a series of overlapping flaps and seals that are rotated as translation occurs along a cam track to form a variable area nozzle section between the flaps and fixed inner contour. (See figure 106). The flaps and seals are hinged to the rear of an actuation ring, and are guided by tracks in the outer support structure. Radial forces generated by flap pressure loads are transmitted through the rollers and largely absorbed as tangential hoop stress in the support. A series of roller bearings in tracks on the outer support structure guide the actuation ring and synchronize the movement of the flaps. The necessary force to move the actuation ring is provided by four hydraulic actuators. By using this translation and rotation concept, the flap rollers can be located near the flap aerodynamic pressure center and, thus, obtain a

nearly-balanced force nozzle. This balancing removes the requirement for large actuation forces. A complete description of the duct heater exhaust nozzle configuration is included in Volume III, Report B, Section IID.

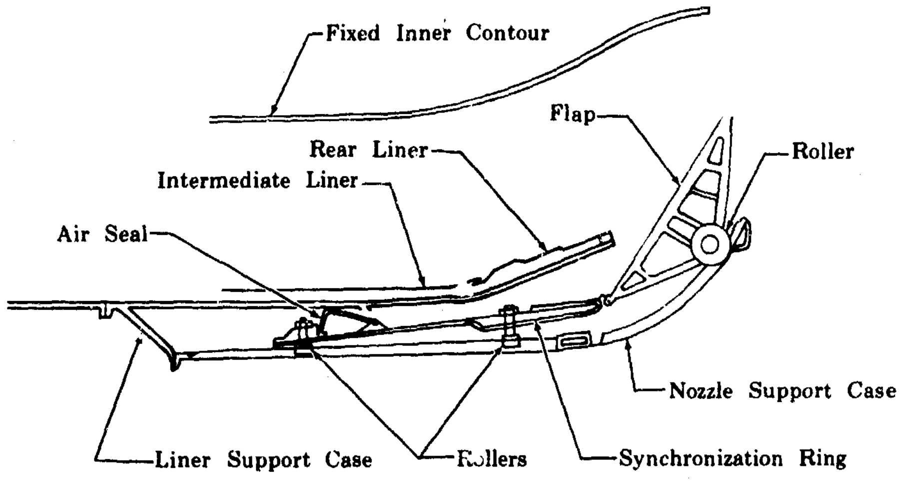

Figure 106. JTF17 Augmentor Exhaust Nozzle FD 16612 EII

The JTF17 variable area exhaust nozzle is essentially the same design used on the J58, and will profit directly from the J58 component development program. Many of the experimental procedures and test rigs described herein are presently being used in the J58 program.

The Phase III nozzle component test program includes extensive tests on rigs to determine problem areas and develop the optimum nozzle configuration. Past experience has shown that the following areas are especially important in a variable area exhaust nozzle development program:

1. Wear of nozzle flap tracks, synchronization ring tracks, flap and seal surfaces, and synchronization ring air seal surfaces.
2. Temperature gradients in flaps, nozzle support case, and synchronization ring
3. Flap and seal gas erosion
4. Nozzle support loading and flexure
5. Synchronization ring loading and flexure
6. Synchronization ring roller and guide track life
7. Flap roller and curved track life.

The test rigs to be used to evaluate exhaust nozzle endurance are described below:

(a) Synchronization Ring Seal Rig

The seal shown in figure 107 prevents exhaust gases from flowing past the synchronization ring toward the front of the engine. The rig used to evaluate the wear characteristics of

the seal is shown in the same figure. In the rig, the seal (a single element) will be translated and the simulated exhaust case will be held stationary as in the engines. The temperature of the combustion duct will be maintained at a level established by engine testing.

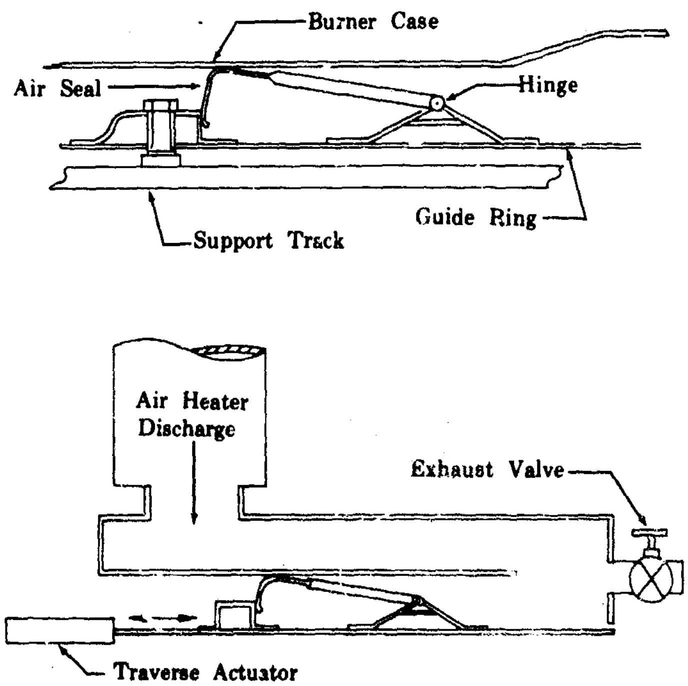

Figure 107. Synchronization Ring Seal Rig FD 16500 EII

(b) Roller and Guide Track Rig

The rig presently being used to evaluate roller and track life is shown in figure 108. In this rig, radial load will be applied to the synchronization ring roller as it oscillates on the track. The movement of the cam is supplied by an eccentric powered by a variable-speed motor. The strain gage is provided to indicate an increase in force required to move the roller bearing should the test piece fail before the end of the test. The oven is provided to simulate environmental conditions of 400°F to 1200°F. At least ten rollers will be tested at each set of conditions to establish a reliable point.

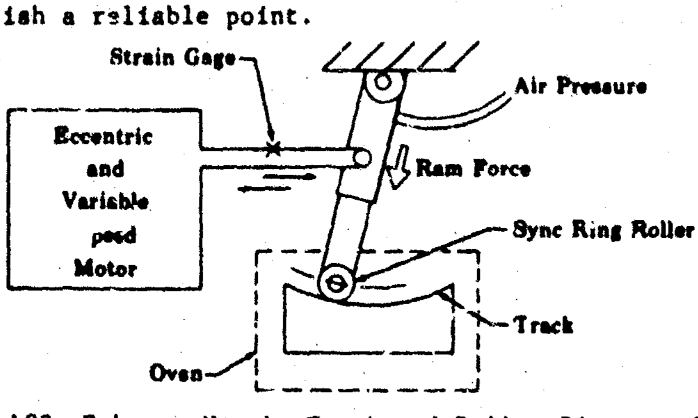

Figure 108. Exhaust Nozzle Track and Roller Rig FD 16502 EII

(c) Static Load Rigs

A static load distribution test on the synchronization ring and nozzle support case will be conducted to determine the stresses produced by the forces from the hydraulic actuators and the flaps. Stress measurement of the nozzle support case will be conducted using the fixtures previously used on the J58 case. This test consists of loading the support case with a series of hydraulic rams applying force at three flap roller contact points, as shown in figure 109.

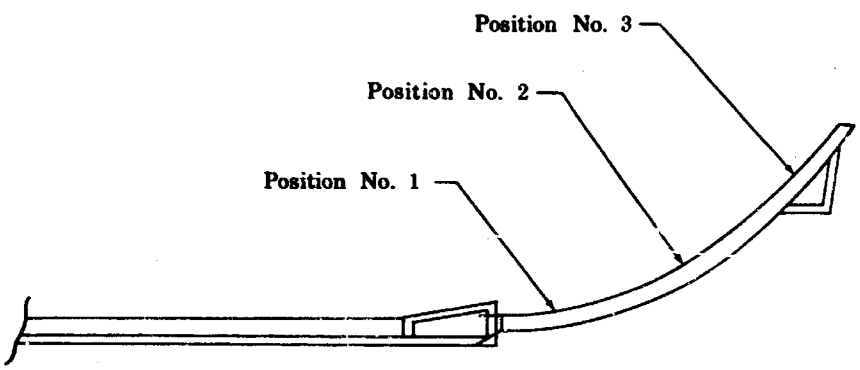

Figure 109. Nozzle Support Case FD 16626 EII

The nozzle support case will be stresscoated to locate areas of maximum stress under radial loads applied separately at three locations on the tracks. Strain gages will be located and oriented in accordance with stresscoat patterns, and strain data will be recorded at each increment of load for the three separate load positions.

The stress analysis on the synchronization ring will be accomplished in generally the same manner as on the nozzle support case. The synchronization ring will be stresscoated and subjected to unbalanced loads from hydraulic actuators. Strain gages are located and oriented according to stress-coat patterns. Deflection, as well as stresses, will be recorded at each load condition.

(2) Reverser-Suppressor

The reverser-suppressor system testing can be categorized into the following areas: (1) structural rigidity, (2) vibratory fatigue, (3) thermal fatigue, (4) wear, (5) air leakage, (6) stability and (7) cooling. All areas, except cooling, can be evaluated with small component rigs. The rigs planned for use in the component development program will be divided into the major elements of the reverser-suppressor, which are:

(1) Blow-in-doors
(2) Clamshell
(3) Trailing Edge Flaps
(4) Secondary Valve

(a) Blow-in-Door Rig

The blow-in-doors must withstand pressure differentials in both directions and impact loads that occur when the doors are slammed against their stops. Effective sealing must be obtained in the closed position to prevent pressure and drag losses. The rig shown in figure 110 will consist of a complete blow-in-door assembly and a hydraulic actuator to open and close the door. The door may be cycled with no pressure differential across the door or, by connecting a metered air supply to the chamber, the leakage flow rate across the seal can be measured.

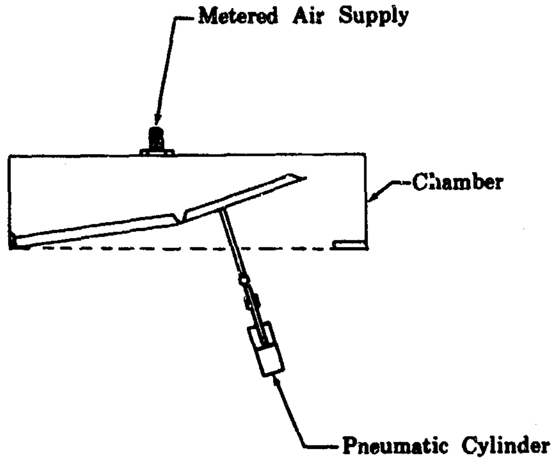

Figure 110. Blow-in Door Test Rig

FD 16627
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(b) Clamshell Rig

Actuation and Interlock Rig

The actuation and interlock system of the reverser-suppressor includes the clamshells, the clamshell actuation system, the clamshell pivot assembly, the sequencing mechanism and the control interlock system.

One major and several smaller rigs will be required. The main test rig will consist of one half of the actuation system mounted on a load simulating framework as shown in figure 111. Means for varying the loads, and cycling is provided by control of the hydraulic actuators. Minor supporting rigs will consist of wear rate, flexure and fatigue laboratory setups for developing the critical parts for the system.

The maximum angle of rotation is approximately 70° with the three operating positions being at 0°, 20°, and 70°. Static load carrying capability is therefore a major concern with fretting between the balls or rollers and their race and brinelling of the races expected to be the life limiting factor. A rig shown in figure 111 which simulates the rig bearing load will be used to evaluate the cyclic life of the pivot bearing. Environmental conditions representative of engine conditions will be maintained during the tests in a manner described in other rigs.

(c) Trailing Edge Flaps

The structure of the trailing edge flaps is subjected to severe loading, both impact and pressure, whenever the flaps go hard against the stops. The flaps are supported at the forward end by hinges and when full open or closed, by the stops which are located at a point approximately two-thirds of the way between the hinge line and the trailing edge. Bending moments occur at both of these support points. The forces act in opposite directions in the open versus the closed positions, resulting in a complete reversal of loads.

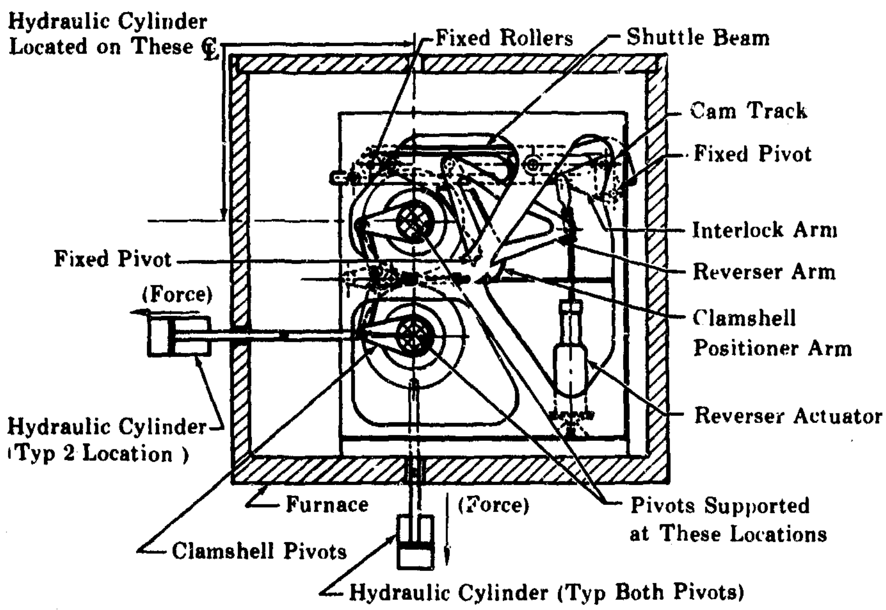


Figure 111. Clamshell Actuation and Interlock Rig FD 16628 EII

Exit Flap Test Rig

Three flaps and the two inter-locking seals will be mounted on a framework to simulate a 1/5 segment of the exit flap assembly as shown in figure 112. The flaps will be enclosed in a pressurized chamber such that pressure can be applied to either side of the flaps. Stress coating, strain gages and dial indicators will be used to measure deflection and stress. Measurements will be taken at differential pressure levels up to 8 psi to determine deflection and stress. Torsional deflection will be measured by locking one edge of a flap and then applying pressure. Low cycle fatigue tests will be run by pressure cycling the flaps between stops. Vibratory fatigue tests will be run by applying natural frequency vibratory loads to the flaps with the flaps both against and free of the stops.

Trailing Edge Flap Stop Rig

The trailing edge flap stops are subjected to various degrees of shock loading and steady load fretting. The bearing or wear areas of the stops and the attachment points to the structure are of particular concern. Durability tests will be run on the simple pneumatic rig shown in figure 113. The rig will simulate maximum impact load to the stops.

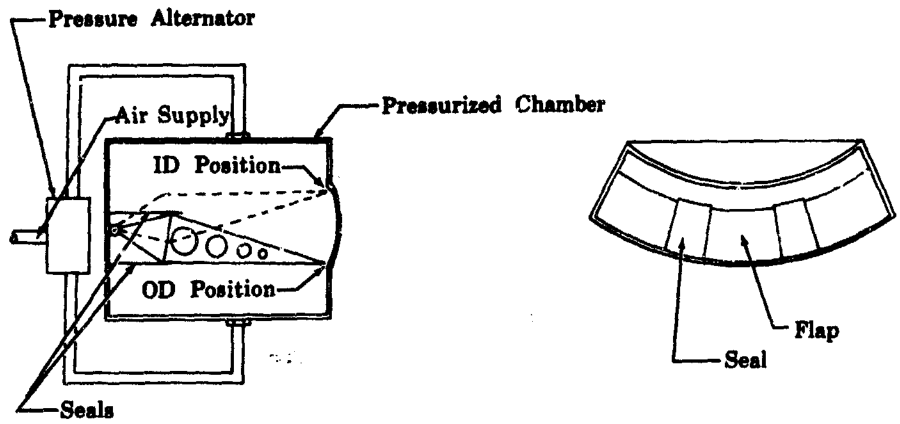


Figure 112. Exit Flap Test Rig FD 16630 EII

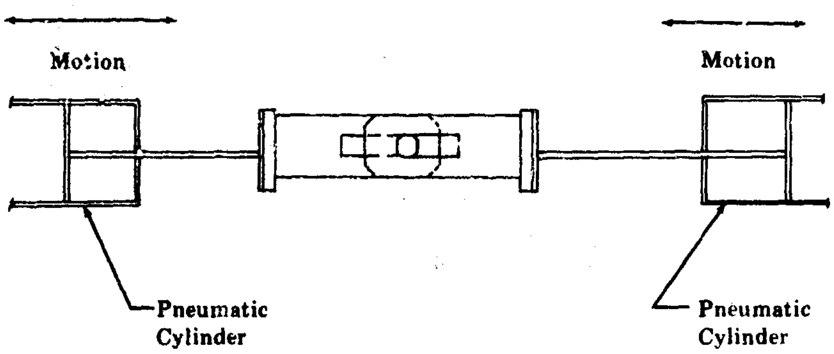


Figure 113. Trailing Edge Flap Stop Rig FD 16631 EII

Thermal Rig

All inner skin surfaces and certain structural members of the clamshells, main component structure and exit flaps are subjected to thermal gradients during subsonic and supersonic operation. The outer skin of the tertiary air doors and inner skin of the side shear panels are thermally loaded during reverser operation. A thermal rig will be used to apply thermal gradients to the trailing edge flaps and to other parts having similar environmental conditions. The rig shown schematically in figure 114 will enable controlled thermal gradients to be applied to the test parts by sizing the fuel-air discharge orifices or separate control valves. Skin thermocouples will be installed on the test piece to determine the magnitude of the gradients. Thermal cycles will be provided by cycling the fuel-air flow rate.

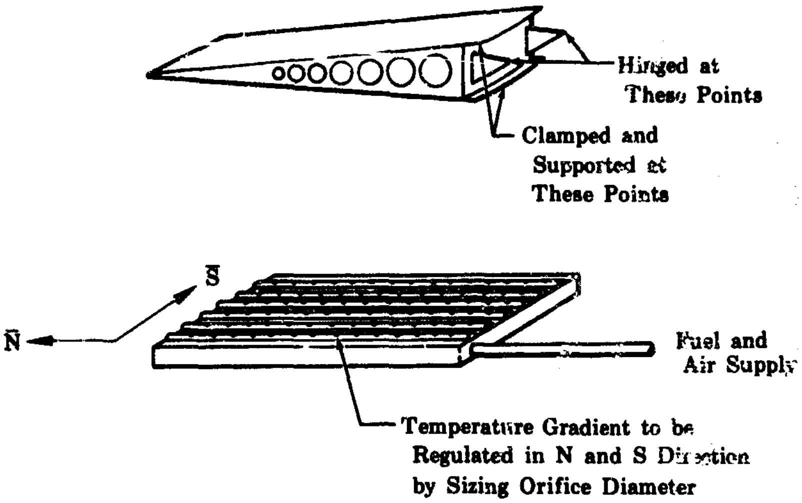


Figure 114. Thermal Buckling and Fatigue Rig FD 16632 EII

(d) Secondary Air Valve

The secondary air flow path must be closed during reverser operation to prevent exhaust gases from entering the engine accessory area. The rig shown in figure 115 will evaluate the cyclic life of the secondary air valve as well as the leakage rate. The valve will be aerodynamically actuated as in the engine. The leakage rate will be measured by halting the pressure signal alternator in one position and measuring the flow rate at the appropriate air bleed.

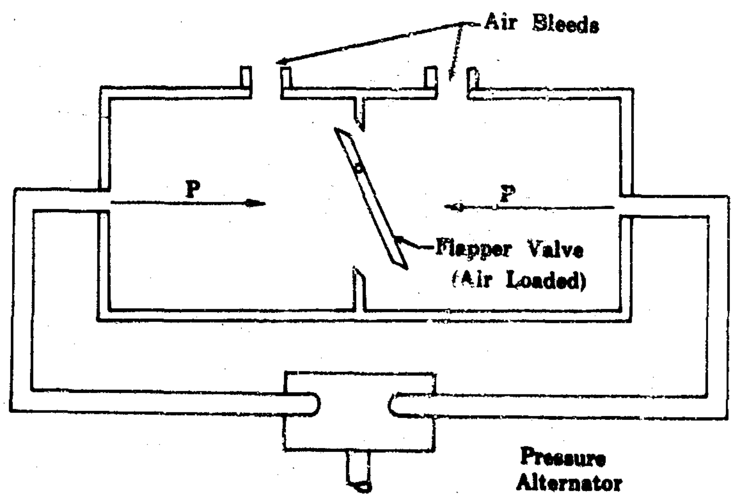


Figure 115. Secondary Air Flapper Valve Rig Schematic FD 16633 EII

In addition to the test apparatus mentioned above, static load rigs will be assembled from existing fixtures to provide structural evaluation of the major structural components of the exhaust system. Stress measurements will be made of structural parts when simulated aircraft maneuver loads and aerodynamic loads are statically applied. The loads will be applied to the component by a series of hydraulic rams.

(3) Aerodynamic Model Testing

The aerodynamic performances of the reverser-suppressors will be established on 1/20 scale models similar to the one shown in figure 116. The test facilities, which are located at FRDC and the UAC Research Laboratories, include a static test stand, a continuous-flow interchangeable subsonic-transonic wind tunnel (figure 117), and a 17 by 17 inch transonic-supersonic blow-down wind tunnel (figure 118). All facilities have a three-flow balance that splits, meters and throttles three concentric flows. The static test stand is capable of metering two concentric streams of either hot or cold gases. A photograph of a reverser-suppressor model mounted in the continuous flow (8' x 8') subsonic-transonic wind tunnel is shown in figure 119.

The important parameters in the exhaust nozzle aerodynamic testing can best be described by subdividing the subject into the three modes of reverser-suppressor operation, that is: tertiary doors closed, tertiary doors open, and reverse operation. A more detailed discussion of the effects of these parameters on performance appears in Report A, Section III.

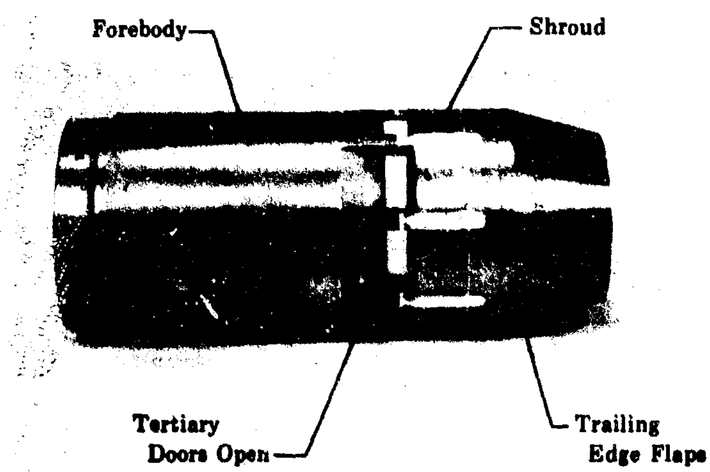


Figure 116. JTF17 Exhaust System Wind Tunnel Model, Tertiary Doors Open — FD 16876 EII

Figure 117. Subsonic-Transonic Wind Tunnel RL 66-171D
EII

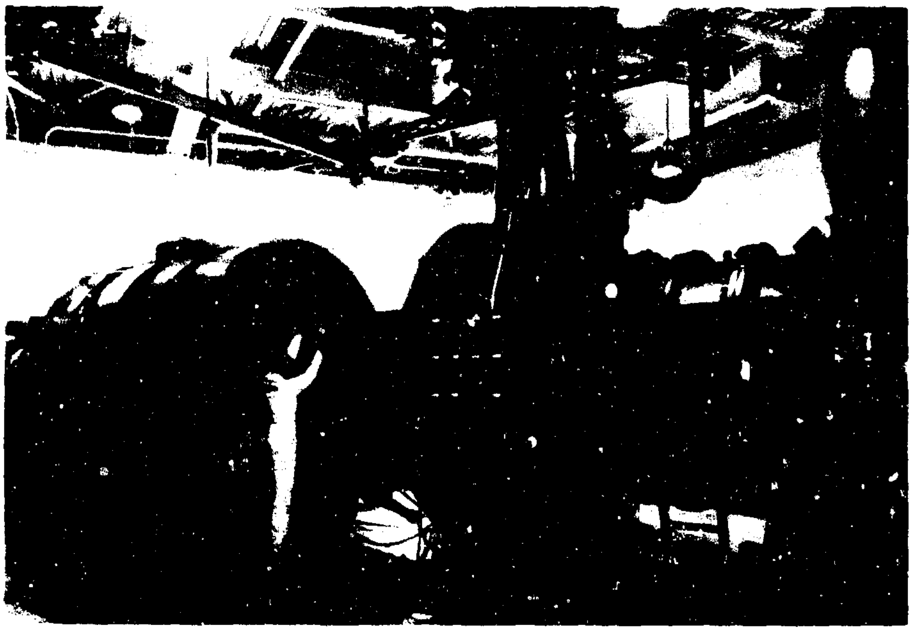


Figure 118. 17 x 17-Inch Transonic Wind Tunnel RL 66-102B EII

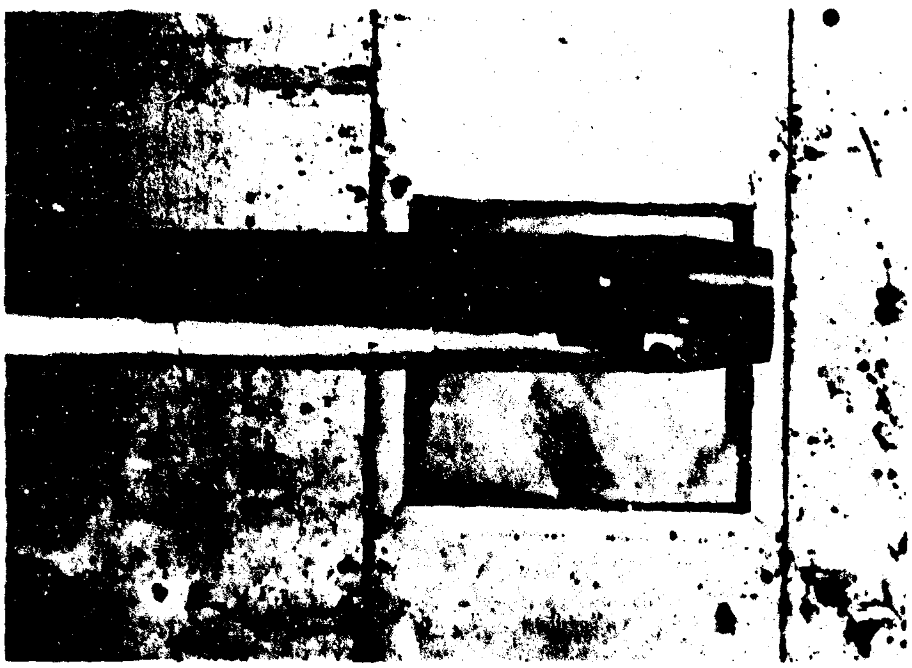
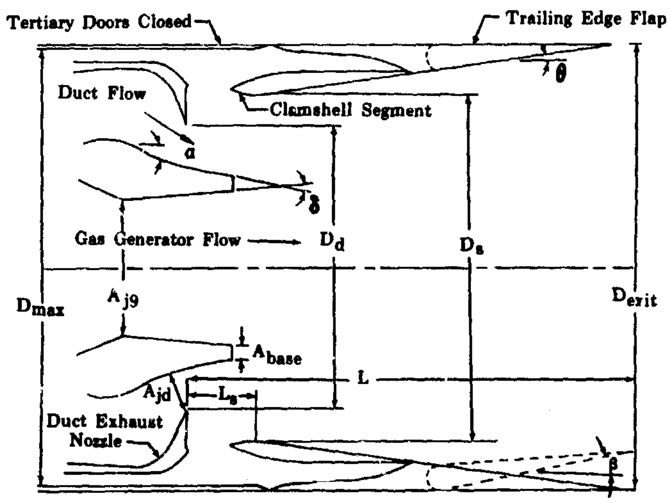


Figure 119. 8 x 8-ft Subsonic-Transonic Wind Tunnel RL 66-171C EII

(a) Tertiary Doors Closed (Cruise)

A nonmixed-flow turbofan engine requires consideration of both gas generator and duct gas streams in the exhaust system design to ensure maximum cruise performance. The design variables that must be taken into account for cruise and associated high Mach number operation are shown in figure 120. The multitude of various combinations of these design variables required extensive wind tunnel testing to establish the effect of each parameter. The following discussion presents the variables and their effect on nozzle performance.



A_{base}	Engine Plug Base Area - ft^2
A_{jd}	Effective Duct Exhaust Nozzle Area - ft^2
A_{j9}	Effective Gas Generator Exhaust Nozzle Area - ft^2
D_d	Duct Exhaust Nozzle Diameter - in.
D_{exit}	Trailing Edge Flap Exit Diameter - in.
D_{max}	Maximum Reverser-Suppressor Diameter - in.
D_s	Reverser-Suppressor Minimum Shroud Diameter - in.
L	Distance from Duct Exhaust Nozzle Tip to End of Trailing Edge Flap - in.
L_s	Exhaust System Internal Spacing; End of Duct Exhaust Nozzle to Minimum Shroud Location - in.
α	Engine Plug Throat Angle; Duct Stream - deg
θ	Shroud Internal Divergence Angle - deg
δ	Duct Flow Impingement Angle - deg

Figure 120. Exhaust System Design Variables, Tertiary Doors Closed   FD 16619 EII

Reverser-Suppressor Maximum Diameter (D_{max})

The reverser-suppressor maximum diameter, D_{max}, is sized at supersonic cruise conditions based on aircraft cruise drag determined from mission analyses. The exit area is sized close to the area required for complete expansion for all streams so that over or underexpansion losses are negligible at cruise conditions.

Shroud Length (L)

The effect of shroud length on performance was determined from test results as well as theoretically from the method-of-characteristics performance deck. Cruise performance is relatively insensitive to small variations of shroud length from the optimum.

Minimum Shroud Diameter (D_s) and Distance from Exhaust Nozzle (L_s)

There is a pronounced interaction between L_s, D_s, and the engine plug that forms the duct stream expansion surface. This is to be expected because the minimum shroud point and plug, and their relative positions, determine the duct stream expansion and the secondary-to-duct total pressure ratio. Also, the duct expansion surface determines the duct exhaust nozzle diameter necessary to obtain the required duct nozzle throat area. Parametric studies have shown that the effect of the minimum shroud location can best be correlated if L_s and D_s are ratioed to D_d. In effect, D_s/D_d is equivalent to an annular area or diameter ratio, and L_s/D_d is equivalent to a spacing ratio. The engine plug is designed with an isentropic contour to balance the static pressure and direction of the duct and gas generator flows at the plug tip.

Engine Plug Angle (α) and Base Area (A_{base})

The plug contour must be designed to provide a static pressure and flow direction balance with the gas generator flow. The choice of a plug angle (α) is somewhat restricted by the required duct and gas generator nozzle flow area. In general it is advantageous to use higher plug angles as long as the flow impingement angle (δ) remains small. Large flow impingement angles can cause oblique shocks and attendant performance lessens. For plugs with no base bleed, the optimum base angle is zero.

(b) Tertiary Doors Open (Acceleration & Subsonic Cruise)

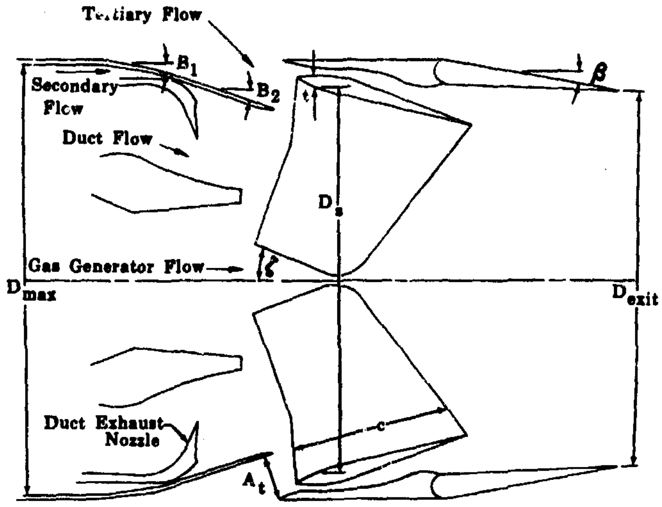
When cruise exhaust system geometry consistent with peak performance levels and good mechanical design has been determinded, the configuration required to obtain high performance during subsonic cruise conditions, i.e., tertiary doors open, must be established.

The geometry variables affecting tertiary doors open operation are tertiary door area (A_t), initial and final tertiary door angle (B_1, and B_2), exit diameter (D_{exit}), trailing edge flap boattail angle (β), clamshell angle (ζ) and clamshell thickness ratio (t/C). These parameters are illustrated in figure 121. Tertiary-doors-open models were tested at Mach 0.9 cruise conditions to establish the effect of these variables on doors-open performance.

Tertiary Door Area (A_t) and Trailing Edge Flap Angle (b)

When selecting values for tertiary door area and trailing edge flap angle, a compromise between overexpansion losses, external pressure drag and tertiary air induction drag must be made to obtain suitable performance levels. An increase in tertiary area improves performance to the point where overexpansion losses are minimized and induction drag due to

tertiary flow starts to become excessive. Maximum trailing edge flap angle must be set so that full expansion takes place at cruise and that overexpansion losses during acceleration are minimized.



A_t	Tertiary Door Area - ft^2
B_1	Initial Tertiary Door Angle - deg
B_2	Final Tertiary Door Angle - deg
c	Clamshell Maximum Chord - in.
D_{exit}	Trailing Edge Flap Exit Diameter - in.
D_{max}	Maximum Reverser-Suppressor Diameter - in.
D_s	Reverser-Suppressor Minimum Shroud Diameter - in.
t	Clamshell Maximum Thickness - in.
β	Trailing Edge Flap Boattail Angle - deg
ζ	Clamshell Angle of Rotation from Cruise Position - deg

Figure 121. Exhaust System Design Variables, Tertiary Doors Open — FD 17004 EII

Clamshell Angle (δ)

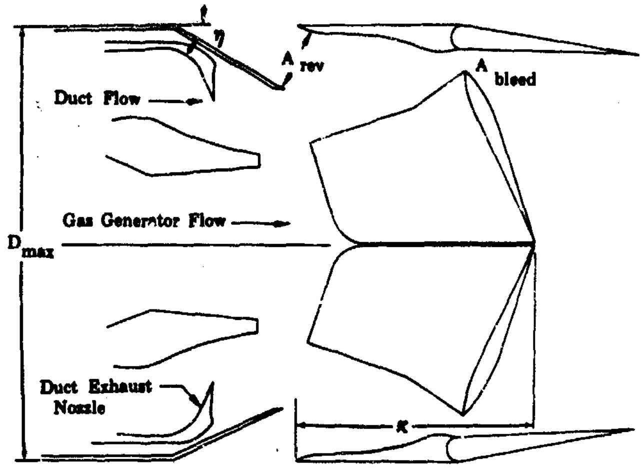
Rotation of the clamshell during tertiary-doors-open operation is required to facilitate the admission of tertiary air. The angle must be large enough to allow the free passage of tertiary air. Excessively large angles will restrict the area behind the clamshell and result in high base drag.

Clamshell Fineness Ratio (t/C)

The effect of clamshell thickness ratio on performance has been found to be slight between the values of 0.03 to 0.10.

(c) Reverse

Figure 122 indicates the design variables associated with reverse operation: reverser discharge area (A_{Rev}), bleed area (A_{Bleed}), spacing ratio (K/D_{Max}) and reverse tertiary door angle (η).



A_{bleed}	Area Between Clamshells and Trailing Edge Flaps at Reverse - ft^2
A_{rev}	Reverse Flow Area Available through Tertiary Doors - ft^2
D_{max}	Maximum Reverser-Suppressor Diameter - in.
K	Distance Along Centerline from Leading Edge of Shroud to Clamshells at Reverse - in.
η	Tertiary Door Angle During Reverse Operation - deg

Figure 122. Exhaust System Design Variables, Reverse Configuration — FD 17003 EII

Reverser Discharge Area (A_{Rev}) and Bleed Area (A_{Bleed})

The reverser discharge area and bleed area must together be selected to achieve the desired value of reverse thrust without suppressing the flow of the duct or gas generator stream. The reverse tertiary door area must be selected as a compromise between the amount reverse thrust obtained and the mechanical complexity envolved in obtaining that area. Bleed area is only as large as necessary to prevent engine flow suppression.

Clamshell Spacing

Reverse thrust coefficient has been found to be relatively insensitive to changes of clamshell spacing, ratio (K/D_{Max}). A more important criteria is the effect of spacing on gas generator flow suppression. A reverser spacing ratio (K/D_{Max}) of 0.5 has been found to produce no suppression of the engine flow.

Tertiary Door Reverse Angle

The tertiary door reverse angle, η, can affect the mean reverse discharge angle and consequently reverser performance. The reverse thrust coefficient has been found to vary with the cosine of the mean reverse discharge angle. The tertiary door reverse angle also affects the separation and attachment characteristics of the reverse gas flow.

(d) Installation Effects

The integration of any exhaust system with an aircraft can affect nozzle performance when the local flow field deviates appreciably from free stream conditions. Installation effects can be minimized on the blow-in door nozzle by giving proper attention to the selection of tertiary door area so that the required tertiary flow is obtained in the localized flow field of the aircraft. Engine placement can alleviate adverse installation effects by providing near free stream conditions.

d. Exhaust Nozzle Test Program

To insure the required performance and durability of the exhause system aerodynamic model tests, component endurance tests and engine tests will be performed. The test programs that will be run in each of these areas are described below:

(1) Aerodynamic Model Tests

Approximately 4600 hours of wind tunnel testing are planned for the Phase III development program to ensure that the exhaust system performance and sound suppression objectives can be met. The 1/20 scale exhaust system models will be tested in the following areas:

(a) Performance Improvement

Approximately 500 test hours will be run to optimize the performance of the current prototype system, including the effect of noise suppression schemes on performance. The model will be tested over the following conditions:

1. Mach 2.7 cruise
2. Mach 1.2 acceleration
3. Mach 0.9 cruise
4. Mach 0.0 takeoff
5. Reverse

(b) Overall Performance Determination

Approximately 2500 test hours will be used to make a complete assessment of the prototype engine reverser-suppressor performance. The tests will be performed over all normal operating conditions with tertiary doors open and closed and with the model in the reverse configuration.

(c) Installation Effects

The scale model will be tested approximately 1000 hours to determine the effects of installation on exhaust system performance. These tests will take into account the effect of the free floating nozzle geometry. The tests will be conducted at simulated subsonic and low supersonic flight conditions where tertiary doors would be expected to be open. Model tests will be conducted to support the engine flight test programs by evaluating the installation effects observed during the flight test program.

(d) Reverser Performance

Approximately 500 hours of model testing will be spent studying the effects of targeting, separation and reingestion on reverser operation and performance. The test conditions simulated for these tests will be:

1. Mach 0.0
2. Mach 0.3
3. Mach 0.6
4. Mach 0.9

(e) Temperature Effects

To determine the effect of the interaction of hot engine flow with the cold secondary flow, approximately 100 hours of tests will be run on the scale models. These tests will be run at supersonic cruise conditions exclusively.

(2) Component Endurance Tests

The endurance of the reverser-suppressor must be developed without the benefit of extensive altitude engine testing prior to engine certification. The accomplishment of endurance objectives will require a substantial test effort on the individual components of the reverser-suppressor such as rollers and tracks on test rigs described previously. Fatigue, vibratory, and strain tests will be run on all parts that are subjected to cyclic loading anticipated in 10,000 hours of normal engine operation. Initially, the tests will be set up to duplicate the predicted loading and environmental conditions. As engine reverser-suppressor data become available the tests will be refined to better reflect engine operating conditions. Configurations that prove their endurance to 10,000 cycles and are candidates for the engine parts list for Certification testing will be tested to 30,000 cycles. All engine reverser-suppressor testing will be carefully monitored and resulting data integrated into the component development program. A total of approximately 35,000 rig hours will be used to evaluate approximately 140 configurations of individual components. A configuration would range in meaning from a complete redesigned part to the application of a special coating to an existing part.

(3) Engine Reverser-Suppressor Testing

Engine will be tested at SLTO, simulated cruise and at actual flight conditions. The objective of these tests are:

1. Sea Level Static

   a. Validate model performance at sea level, static
   b. Evaluate durability features in normal and reverse mode
   c. Provide information necessary to improve maintainability and to establish parts service limits
   d. Determine temperature of structural parts.

2. Simulated Cruise (AEDC) Testing

   a. Provide internal reverser-suppressor performance at cruise conditions.
   b. Provide internal performance data at off design conditions
   c. Evaluate parts durability at simulated flight conditions
   d. Determine temperature of structural parts

3. Flight Testing

   a. Determine internal and external performance of reverser-suppressor
   b. Measure temperature of structural parts
   c. Compare Blow-in door and trailing edge flap position with predicted value
   d. Evaluate effect of installation on reverser-suppressor performance

These programs are discussed in detail in the engine test program (Volume III, Report E, Section III), FTS test plan (Volume III, Report E, Section IV) and the engine flight test plan (Volume III, Report E, Section V).

e. Component Test Schedules

Overall time-sequence charts for the exhaust system development are shown in figures 123 and 124. Schedules of individual component rig hours are shown cumulatively in figures 125 through 130.

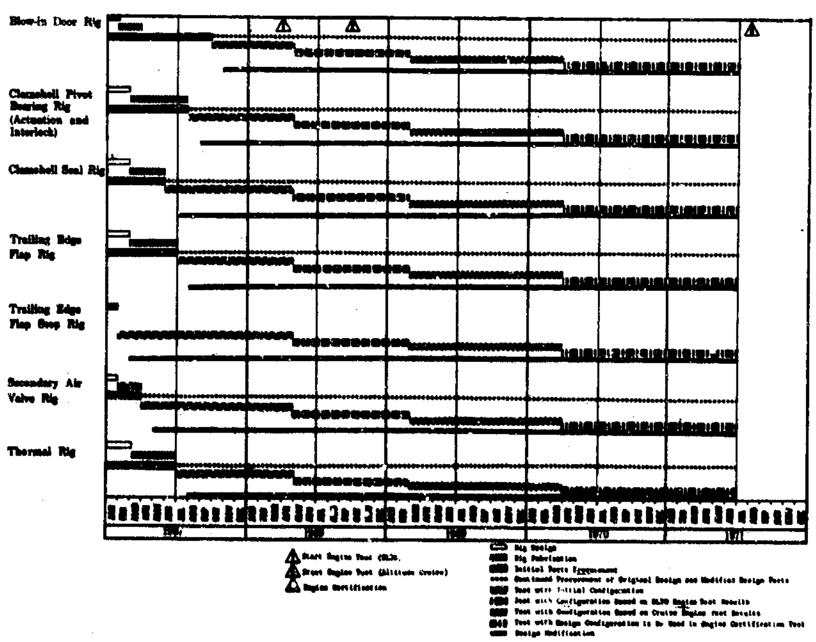


Figure 123. Reverser-Suppressor Component Test Stand

FD 17005
EII

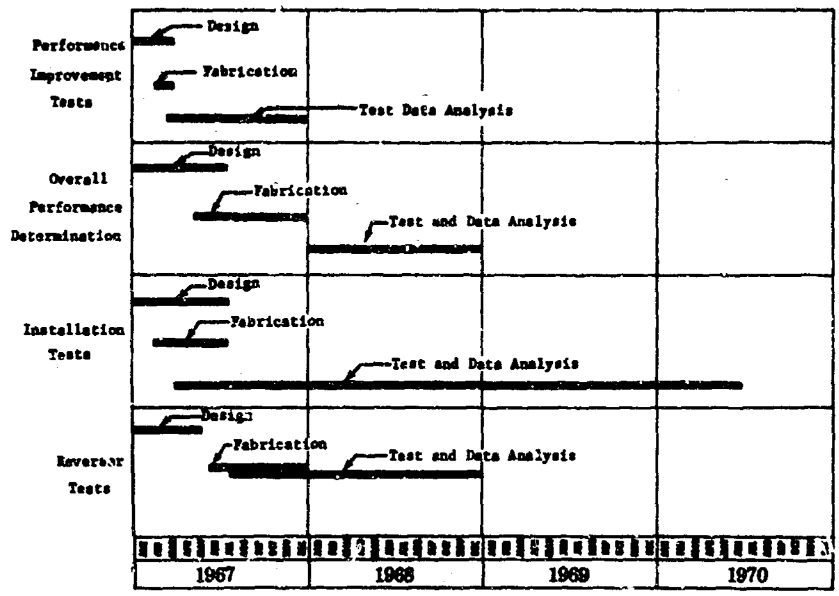


Figure 124. Aerodynamic Model Test Schedule FD 17006
EII

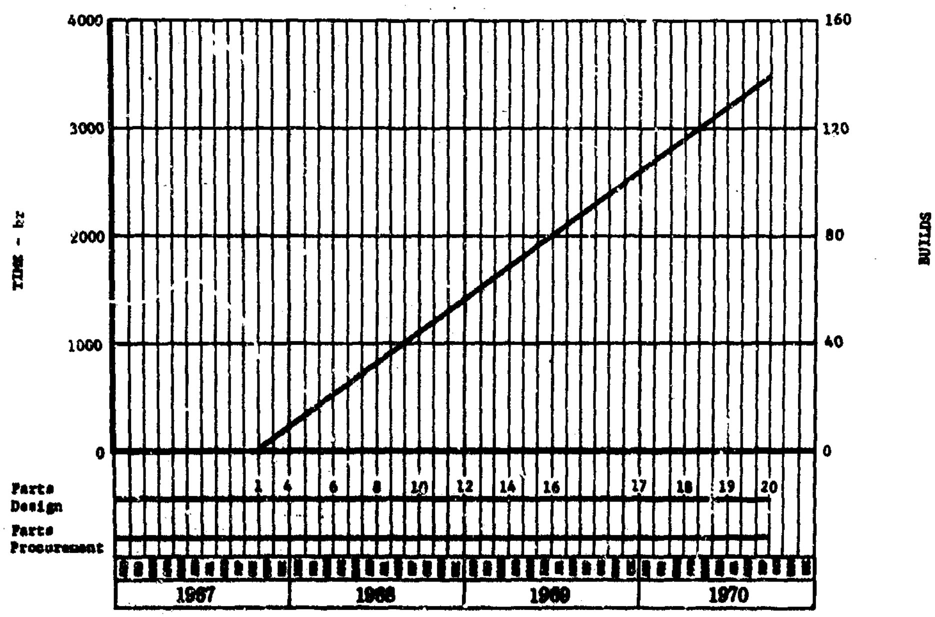


Figure 125. Blow-in Door Rig Schedule FD 17007
EII

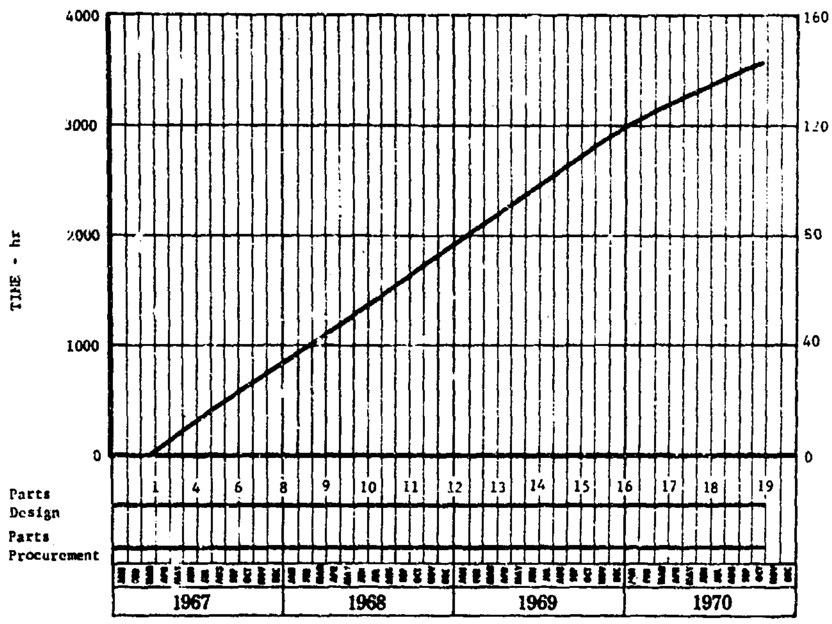


Figure 126. Secondary Air Valve Rig Schedule FD 17008 EII

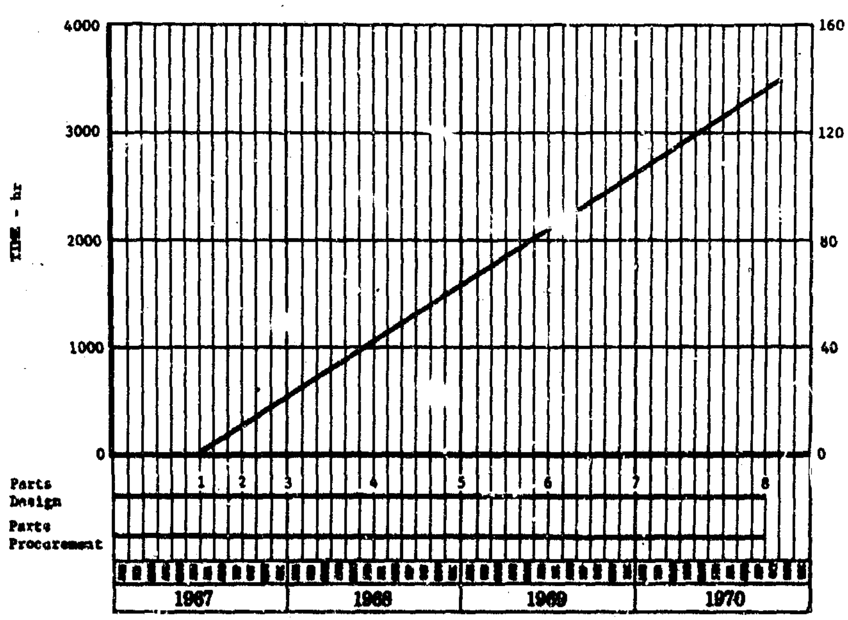


Figure 127. Clamshell Pivot Bearing Rig FD 17009 EII

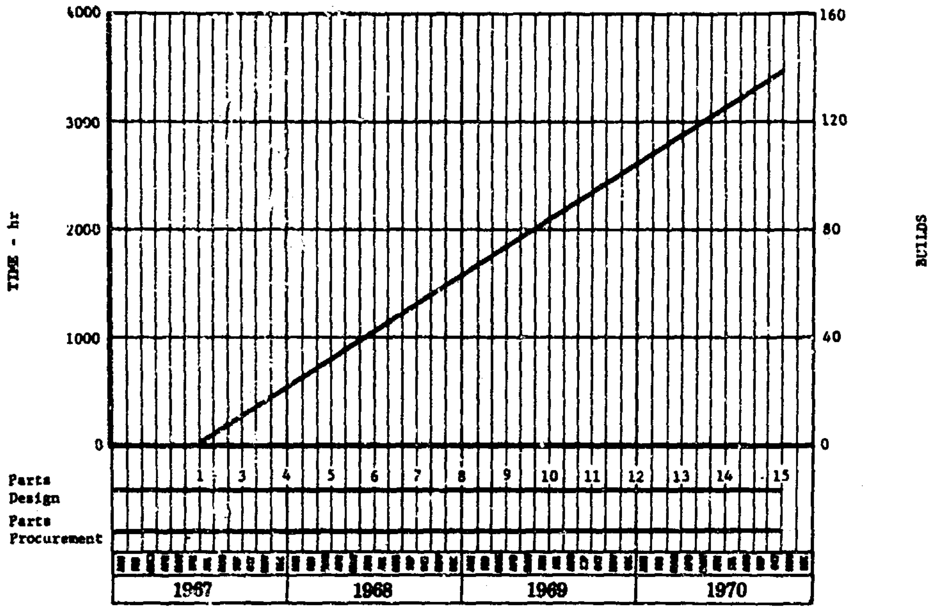


Figure 128. Trailing Edge Flap Rig Schedule FD 17011 EII

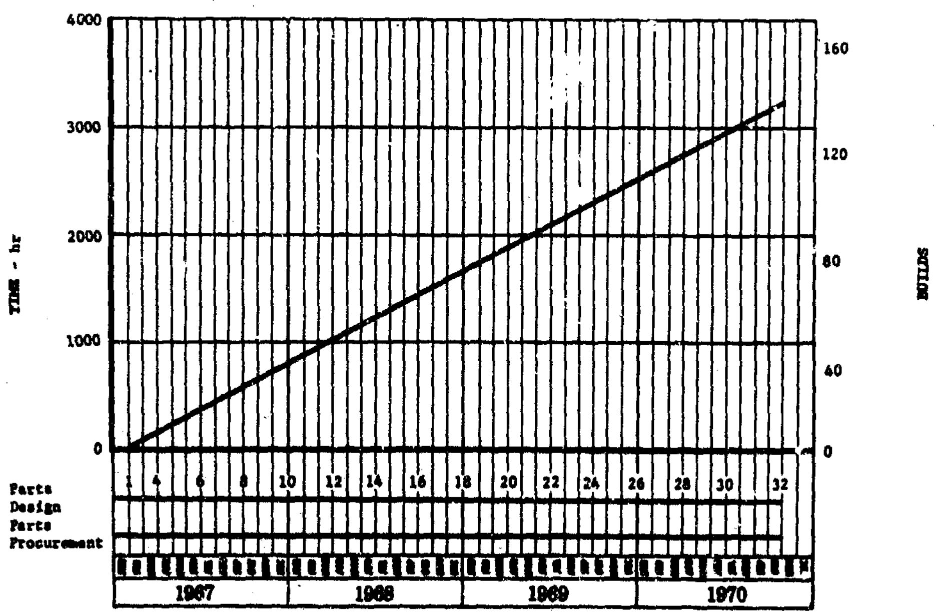


Figure 129. Trailing Edge Exit Flap Stop Rig Schedule FD 17012 EII

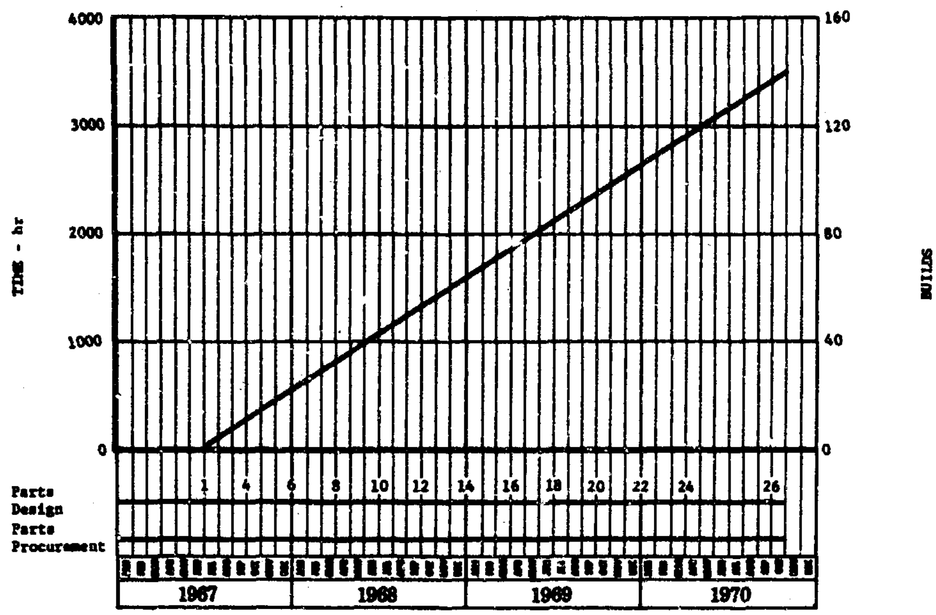


Figure 130. Thermal Rig Schedule

FD 17013
EII

7. Bearings, Seals, and Gearboxes

a. Introduction

Because of the unique design features of the JTF17, which supplies fan discharge air to separate the bearing compartments from the surrounding higher temperature air, and the control of oil temperature to levels compatible with the Jet II type, all bearings and seals will operate, even at Mach 2.7 cruise, at environmental conditions no more severe than in current commercial fan engines. This section describes the planned Phase III component test programs for the JTF17 engine bearings, seals and gearbox system to verify these designs. These systems are closely related in that the main shaft bearings accept the full radial and thrust loads, speed, and accelerations of the two engine rotors and transmit the required horsepower to the accessory gearboxes; and the engine seals separate the bearing compartments and gearboxes from the high temperature and pressure engine air. To demonstrate that the JTF17 bearing, seals, and gears have the desired performance and durability throughout the engine operating range, over 38,000 hours of testing in fourteen bearing and seal test rigs is planned for Phase III. In addition to these fourteen rigs, which consist of individual bearing and seal rigs and full scale engine bearing compartment seal rigs, a single integrated lubrication and gearbox subsystem rig consisting of a "bladeless" engine with the engine bearing compartments and gearboxes will be tested for evaluation and development of the entire engine lubrication, bearing, seal and gearboxes.

Although the components in this section are closely related during engine operation, the development programs are presented in separate subsections, for ease of presentation and understanding.

b. Bearing Program

(1) Background

To ensure that the JTF17 engine will meet FTS, Certification and TBO requirements, the bearing test program is directed toward evaluating various bearing characteristics of each of the four main engine bearings and the towershaft bearings. All such bearings are procured from Engineering Approved vendors. Except for provisions for positive race retention, all designs and materials are the same as used in the J58 engine for Mach 3 continuous cruise operation. A general description of the engine bearings is as follows.

(a) No. 1 Bearing

The No. 1 bearing is a flanged outer race, split inner race, deep groove, ball thrust bearing transmitting the forward fan rotor thrust to the front of the engine intermediate case The bearing race and ball material is M-50 tool steel, consumable electrode vacuum arc melted (CVM). The bearing cage material is silver plated AMS 6415 steel. Bearings manufactured by two vendors will be tested, one of which supplies all J58 main thrust bearings.

(b) No. 2 Bearing

The No. 2 bearing is a deep groove flanged outer race, split inner race, ball thrust bearing located at the forward end of the high speed compressor rotor. This bearing transmits the rearward thrust of the compressor rotor to the rear of the intermediate case. This bearing is also manufactured by two vendors and is made of the same race, ball, and cage materials as the No. 1 bearing.

(c) No. 3 Bearing

The No. 3 bearing is a high speed, preloaded roller bearing that provides the radial support for the rear of the high rotor. The test program to be run on this bearing will include a substantial amount of cage and oiling scheme evaluation. Alternative materials and vendors are utilized for this bearing. The alternate bearing race and ball materials are consumable electrode vacuum arc melted Bower 315 and M-50 tool steels. The cage material from both sources is AMS 6415 steel.

(d) No. 4 Bearing

The No. 4 bearing is a preloaded roller bearing located aft of the engine turbine to radially support the rear end of the low rotor. This bearing is made of the same materials as the No. 3 bearing and is procured from two vendors.

(e) Towershaft Bearings

Ball and roller bearings are used to support the thrust and radial loads of the accessory drive towershafts. All of the towershaft ball bearings are made of CVM, M-50 tool steel, and the roller bearings are made of either CVM Bower 315 and M-50 tool steel. All towershaft bearing cage materials are AMS 6415 steel.

The general scope of the bearing development testing for the JTF17 includes: (1) bearing performance tests to determine adequacy of bearing design and define optimum oil flow rates; (2) durability testing, which includes oil shut off tests, dirty oil tests, and overspeed tests; (3) development testing that includes defining the most probable failure mode for the bearing and working to increase the life and performance of that element of the bearing; (4) endurance testing to define the bearing B-10 life and reliability limits; and (5) component improvement in support of the experimental, production and service programs.

(2) State-of-the-Art

(a) General

Pratt & Whitney Aircraft's experience with rolling element bearings is varied and extensive and includes many flight engine types in military and commercial applications, as well as industrial versions of turbojet engines. Flight experience on antifriction bearings exceeds one billion bearing hours. Many sizes of antifriction bearings are used in these engines, ranging from large mainshaft bearings to gearbox accessory bearings and even smaller control bearings. This experience includes various designs of radial roller bearings and ball bearings. Bearings used by Pratt & Whitney Aircraft in military and commercial service have, over the years, shown excellent reliability. This dependability is the result of: (1) extensive bearing development, endurance testing and material property and quality improvements to increase the mean time to failure, (2) designing the bearing compartment to protect the bearings from corrosive atmosphere and dirt, (3) operating at the lowest oil temperatures with the lubricants compatible with high performance, (4) extreme accuracy of application and installation and flexible housings to minimize the effects of misalignment, (5) the inherent overload capacity of antifriction bearings, (6) the inherent resistance of these bearings to Brinelling damage, and (7) the inherent ability of these bearings to accept full loads, speeds, and accelerations for finite periods without oil.

The success of these applications is the result of an extensive analytical, and experimental effort over many years. A complex analytical design system has been developed through correlation of experimental test results which has led to great improvements in bearing design. A time-tested temperature and heat generation prediction system has evolved from the analytical and experimental effort and has permitted the design of highly advanced bearing systems. Unique oil cooling arrangements have been developed and are successfully being employed in advanced engines that are presently operational.

The Bearings and Seals Group at Pratt & Whitney Aircraft conducts continuous studies and evaluations of bearing and seal characteristics. This continuing program makes available a vast storehouse of knowledge at any time for the solution of unique problems that may arise. This program and experience gained on the Mach 3+ J58 high temperature engine furnish the "building blocks" for the bearings and seals currently being used in the JTF17 engine.

Bearing development testing covers the entire spectrum of bearing types. To supplement this experimental effort, a number of experienced analytical engineers are available to provide design and prediction systems using the latest in high speed digital computing equipment. Outside research is sponsored by Pratt & Whitney Aircraft to study fundamentals of bearing friction, wear, and fatigue at MIT, Battelle Institute and Illinois Institute of Technology. In addition, cooperative research and development programs are carried out with several bearing vendors and bearing material manufacturers.

The extensive bearing research and development programs by Pratt & Whitney Aircraft have generated numerous benefits of value to the overall JTF17 bearing program. Among these are the following:

1. Development of a superior bearing oiling system by introducing the oil through the split bearing inner race at the point in the bearing where the majority of the bearing heat is generated. This oiling scheme results in:

   a. Reduced oil flow by efficient use of the oil
   b. Reduced lubricant charring by the use of reduced, regulated oil flow to the bearing
   c. Complete contact area coverage
   d. Reduced bearing temperature by reduction in heat generated by friction.

2. Development of an out-of-round bearing race for preloading large high-speed, lightly-loaded roller bearings to prevent skidding.
3. Development of bearing failure indicators that reveal fatigue failures before temperature or vibration is affected, and yet are insensitive to unrelated ambient conditions.
4. Development of new bearing material (a consumable electrode vacuum arc melted steel) with grain flow control resulting in 10,000-hour bearings in high performance aircraft.
5. Cyclic oil interruption bearing tests resulting in cage designs which are lighter, stronger, less costly, and have the ability to withstand over 200 oil shutoff cycles as compared to less than 10 for conventional design.
6. Lubrication and bearing fatigue programs of over 7000 hours per configuration, resulting in correlation of lubricant effect on a particular bearing design and material.
7. Verification that ball fatigue life is an inverse function of ball spinning from over 13,000 hours of testing in the Pratt & Whitney Aircraft V-Groove Ball Fatigue Measuring Machine.
8. Development of a ball-plate fatigue testing program which has evaluated bearing steels under conditions of pure rolling contact fatigue and found stress levels of from 370,000 psi to 525,000 psi, at temperatures up to 400°F during over 7500 hours of testing.

9. Development of a computer program providing a means for computing the kinematics of the ball, the forces and moments acting on the ball, the elastic characteristics of the balls and races, the power generation due to ball spin friction, the spin and roll rotational velocities of the ball with respect to the races, the B-10 (AFBMA) life, and the B-10 life with centrifugal ball loading effects taken into account. This program has provided a means of studying the effects of various geometry variable on bearing performance.
10. Development of a test rig and instrumentation for the study of critical speed phenomena in shafting. The device is built with a cantilever shaft, and has capacitance pickups for measuring shaft displacement.

(b) JTF17

The same basic bearing design standards utilized in the successful commercial JT3, JT4, and JT3D engines and in the high performance military TF30 and J58 engines has been used in the JTF17 bearing design. These design features in the JTF17 are the latest in the state-of-the-art as previously described. Grain flow is specified for the thrust bearing races to conform to the race curvature. The balls will contact the race on the side-grain instead of end-grain. The bearing cages incorporate completely premachined pockets which require no subsequent forming of material to retain the balls. The same AMS 6415 steel, silver plated bearing cages used in the TF30 and J58 engines are also used in the JTF17 engine bearings. This material results in higher temperature capability, greater strength, lower weight, and a coefficient of thermal expansion closer to that of the bearing race and ball material. Although the JTF17 bearings are basically the same as in other P&WA high performance engines, a complete evaluation and development program is required for Phase III to verify the designed-in reliability of the bearings in the JTF17 engine for commercial engine service.

(c) Present Phase II-C Component Status

During Phase II-C, more than 73 hours of engine testing, including operation at Mach 2.7, 65,000 feet cruise condition, were completed on the JTF17 engines through July 1966. These test hours have verified that the mainshaft and accessory towershaft drive bearing designs were sound. It is significant that there have been no bearing problems. The component verification rig test program has progressed to the point that the main engine compartment bearings have been evaluated in full scale bearing compartment rigs at simulated engine operating conditions up to Mach 2.7, 65,000 feet cruise conditions for a total of 90 hours through July 1966. The No. 2 high compressor thrust bearing completed an additional 42 hours of calibration tests at 325°F oil inlet temperature, rotor speeds from 4400 rpm to overspeed conditions up to 8800 rpm, thrust loads from 2200 pounds to overload conditions of 20,000 pounds, and at varying oil flows of 25 ppm ± 5 ppm. All testing was conducted with type II oil meeting the requirements of the engine specification. Thermal performance data verified the analytical computer calculated bearing performance estimates as well as the bearing design.

The basic design difference in the JTF17 Phase III bearings from the Phase II-C design is the flanging of the bearing outer races to prevent race spinning with a slight increase in weight. Although no outer race spinning was noted during Phase II-C, this feature was added after extensive review of commercial airline bearing troubles indicated that a large percentage of the failures and damaged bearings were a result of race spinning. No significant problems are foreseen in the development of flanged races. Bearing vendors assure that fabrication dates and quality control will be met.

(3) Component Development Test Program Objectives

The objective of the overall bearing test program is to ensure that the JTF17 engine will meet the FTS, Certification and TBO requirements. This program will be directed toward evaluating and developing bearing performance and durability characteristics of each of the four main engine bearings and the towershaft bearings. The objectives of these bearing tests include the following:

1. Determine the thermal performance of the bearing under the anticipated operating condition.
2. Determine the bearing oil flow requirements.
3. Determine bearing durability, including cage wear.
4. Measure cage speed to map the skidding range.
5. Determine oil shutoff performance, including effect on the cage and riding surfaces, to substantiate durability.
6. Determine bearing overspeed limits.
7. Determine B-10 life of the bearing to determine reliability.

The test sequence has been established to minimize repetitive testing caused by design changes. The program will deliberately force early failures and establish the most likely failure modes. Early failure mode definition allows design changes to be made prior to final durability or endurance tests so that delay in JTF17 engine milestones will be avoided.

(4) Description of Component Test Rigs.

The thrust bearing rig used in Phase II-C will be utilized for the JTF17 thrust bearing program in Phase III. A schematic of this rig is shown in figure 131. In this rig, the rear test bearing is loaded against the front test bearing by a hydraulic thrust load applied on the outer housing of the rear bearing. A splined shaft drives the rig from an external drive motor. The inner race hub and outer race housing are designed to simulate the engine bearing compartment and the lubrication system duplicates the engine oil system as much as possible. The inner rotating race temperatures are measured by bringing the signals out through a slip ring assembly that mounts on the front of the rig. A complete thrust bearing rig is shown on D-1 test stand in figure 132.

Modification to the design of existing J58 roller bearing rigs is required to test the JTF17 engine roller bearings. A schematic layout of the roller bearing rig to be used to test the JTF17 No. 3 and No. 4 roller bearings is shown in figure 133. The radial load applied on the outer race of the front test bearing by a hydraulic load cylinder is

transferred through the hub. This in turn causes the rear test bearing inner race to be loaded against its stationary outer race. The roller bearing rig simulates engine parts and lubrication schemes as much as possible. The drive power is supplied by an external drive motor through a step-up gearbox to run at the proper speeds.

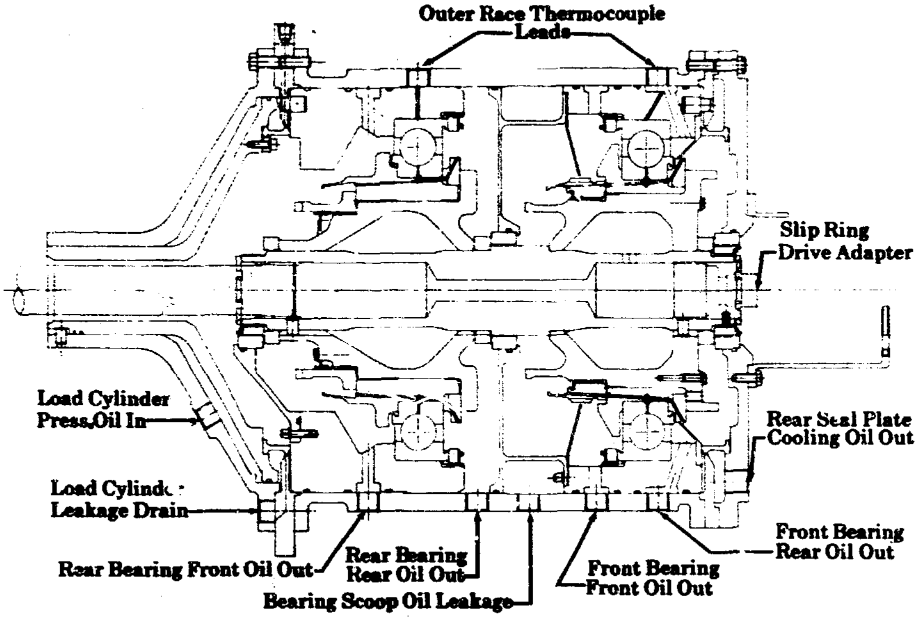
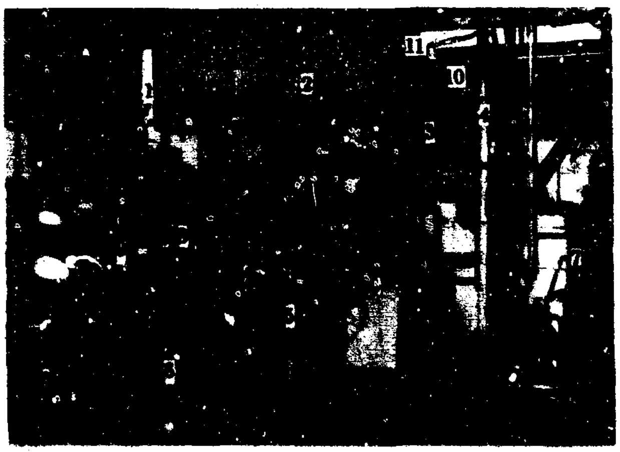


Figure 131. Schematic Diagram of Thrust Bearing Test Rig FD 16536 EII



1. Drive Motor
2. Drive Gearbox; 3.4.1 Step Up Ratio
3. Test Rig
4. Slipring for Thermocouples on Bearing Inner Rings
5. Pump and Motor Supplying Oil to Loading Cylinders
6. Pumps and Motor Supplying Oil to Gearbox and Scavenging Oil From Sump Tank
7. Pump and Motor Supplying Oil to Test Rig
8. Oil Line to Gearbox
9. Coolers for Test Rig Oil
10. Thermocouples on Bearing Outer Rings
11. Oil Line to Test Bearing

Figure 132. Typical Thrust Bearing Rig and Test Stand FD 16810 EII

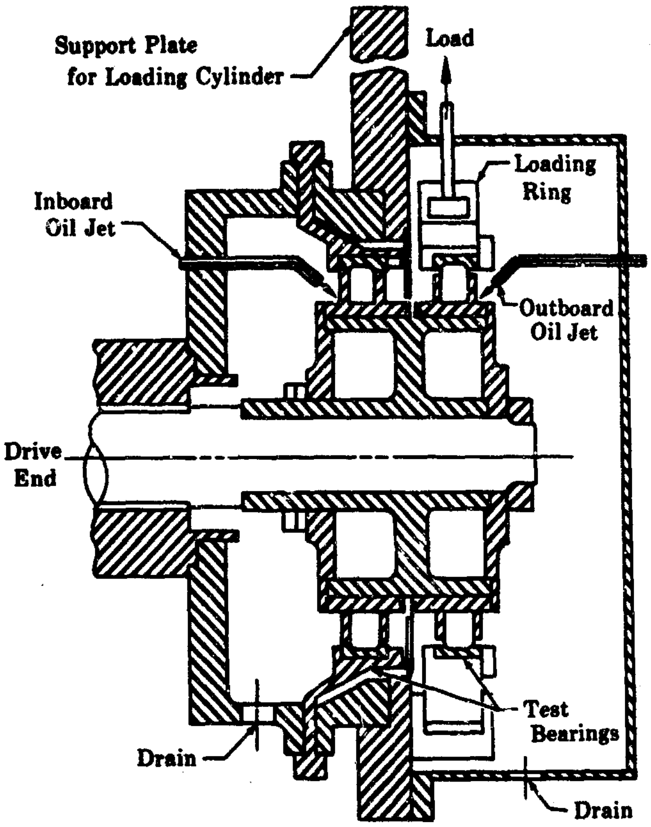


Figure 133. Schematic of Roller Bearing Rig FD 16537 EII

(a) Failure Indicators

Unique bearing failure indicators have been developed by Pratt & Whitney Aircraft utilizing semiconductor accelerometers. The accelerometers are mounted in the horizontal and vertical axes at both the front and rear of the bearing test rig. Monitoring of the rig vibration with the failure indicator meters allows a test termination before a bearing failure becomes catastrophic. These failure meters have been placed on some experimental engines in the thrust bearing compartments to monitor incipient bearing failures.

(b) Test Facilities

The test facilities required for the development and evaluation of the JTF17 bearings consist of currently available test stands in the small component test laboratory at FRDC. These test stands utilize drive motors, oil tanks, heat exchangers, flow meters, control valves, filters, and provisions for complete pressure and temperature instrumentation.

(5) Component Test Programs

The following JTF17 bearing development tests are planned to ensure that the engine meets FTS, Certification and TBO requirements.

(a) Ball Thrust Bearing Calibrations

The objective of these tests is to determine the operating characteristics of the engine bearings under simulated engine conditions. Oiling schemes, cage design, material, and lubricants are also evaluated. The thrust bearings from both vendors are run in the test rig with loads, speeds, oil flow, and oil temperature varied within the engine operating range and slightly beyond. The oil heat rejection is determined by measured oil temperature rise and oil flow. Operating temperatures are measured by thermocouples mounted on inner and outer races. These tests will provide data in sizing oil flows and limiting heat rejection and race temperatures in the design of the bearings and the bearing compartments.

For the No. 1 and the No. 2 thrust bearings, six calibration tests on each vendor's bearings are proposed. Each test is approximately 50 hours in duration, utilizing new bearings for each test. The actual total number of tests required will depend upon the number of design changes to the bearings. Early calibration tests are planned to enable the final bearing design to be made prior to endurance testing.

(b) Roller Bearing Calibrations

These tests are similar in nature to the thrust bearing program described above. The same type heat rejection oiling scheme and bearing design data are obtained and evaluated to improve the operation of the bearing if required.

Past experience has shown that fewer bearing calibration tests are required on roller bearings prior to the final design than on thrust bearings; therefore, only three calibration tests on both vendor roller bearings are proposed. These tests also are planned early in the schedule to finalize the design prior to endurance testing.

(c) Oil Shut-Off Tests

One of the areas for consideration in developing a long life anti-friction bearing is the ball retainer or cage. An improperly designed cage may cause skidding, less efficient lubrication and cooling, and failures if the cage is not strong enough for the specific application. The oil shut-off bearing test developed by Pratt & Whitney Aircraft has been highly successful in evaluating the bearing cage design. The bearing, with the cage to be tested, is subjected to cyclic oil interruptions of one minute over the speed, load, and oil temperature operating range of the bearing. A properly designed bearing should withstand over 200 oil shut-off cycles.

Three design verification tests of both vendors' bearing in each compartment is scheduled after the bearing calibration tests have been completed early in the program. Each test will use a new bearing and last approximately 20 hours.

(d) Overspeed Tests

One of the most demanding requirements of turbojet engine bearings is to operate at high rotor speeds and DN values (product of bore in millimeters and speed in rpm). The JTF17 main shaft bearings are required to operate at maximum DN values up to 1.89×10^6 for the No. 3 roller bearing as compared to 1.40×10^6 for the JT3 and JT4 engines. To ensure that the JTF17 engine bearings will operate at their designed DN, a total of six overspeed tests will be run on the bearings in each location. The bearings will be required to operate successfully at full loads and speeds starting at the maximum engine speed and then to approximately 25 percent overspeed for 10 hours.

(e) Simulated Environmental Tests

Bearing compartment seal rigs have been designed and built during Phase II-C to simulate each compartment at all engine operating conditions. The bearings are to be tested and evaluated under these conditions in Phase III during 150, 500 and 1000 hour tests. These tests will consist of typical JTF17 flight cycle simulated environments. For a complete description of these rigs see Volume III, Report E, Section III.

It is estimated that a total of four bearings from each compartment will be required for these environmental endurance tests. Two tests of each compartment are scheduled to be completed early in the program to evaluate the basic compartment design and three additional endurance tests to be completed within four months of FTS.

(f) B-10 Life Testing

Fatigue life for rolling contact bearings is statistical in nature; that is, individual bearings may fail at different times under the same load and speed conditions, resulting in a failure-time distribution. Fatigue life is normally spoken of at the 10 percent level, AFBMA L10 or B-10 life, which is the time at which 90 percent of the bearings will have survived, or 10 percent will have failed. To determine the B-10 statistical bearing life of the two JTF17 engine thrust bearings, 500-hour endurance tests will be run on ten bearings each procured from both vendors of each bearing. These tests are run at maximum cruise speed and overloads to give an expected 5 times AFBMA life. These tests are scheduled to begin after initial calibration tests have confirmed the bearing design and end prior to FTS.

The Phase III total JTF17 bearing program test hours per bearing location, number of tests, number of bearings re[illegible] and the total number of bearing rigs are shown in table 13. The te[illegible] hours accumulated include those from bearing compartment seal rigs as well as those for bearing rigs. The proposed scheduling of the bearing testing is shown in figure 134.

Development testing will continue after FTS at a reduced rate of 3600 bearing test hours per year until engine type Certification. The component inprovement bearing program will start after FTS and continue through Phase IV. The purpose of this Phase IV testing will be to increase bearing

Table 13. Phase III JTF17 Bearing Test Program

Test Description	No. 1 Thrust Bearing		No. 2 Thrust Bearing		No. 3 Roller Bearing		No. 4 Roller Bearing		Towershaft	
	Test No.	Test Time (hr)	Test No.	Test Time (hr)	Test No.	Test Time (hr)	Test No.	Test Time (hr)	Test No.	Test Time (hr)
Calibration of 1st Vendor's Bearings	1-6	200	1-6	300	1-3	150	1-3	150	1-3	150
Calibration of 2nd Vendor's Bearings	7-12	200	7-12	300	4-6	150	4-6	150		
Oil Shutoff Test of 1st Vendor's Bearings	13-15	60	13-15	60	7-9	30	7-9	30	4-6	60
Oil Shutoff Test of 2nd Vendor's Bearings	16-18	60	16-18	60	10-12	30	10-12	30		
Overspeed Test of 1st Vendor's Bearings	19-21	30	19-21	30	13-15	30	13-15	30	7-9	60
Overspeed Test of 2nd Vendor's Bearings	22-24	30	22-24	30	16-18	30	16-18	30		
Simulated Environmental Tests of 1st Vendor's Bearings	25-27	1500	25-27	1500	19-21	1500	19-21	1500	10-11	1500
Simulated Environmental Tests of 2nd Vendor's Bearings	28-29	500	28-29	500	22-23	750	22-23	650		
B-10 Life of 1st Vendor's Bearings	30-39	5000	30-39	5000						
B-10 Life of 2nd Vendor's Bearings	40-49	5000	40-49	5000						
		12,580		12,780		2670		2570		1770

life and reliability. This program will work on bearing problems which may occur on experimental engines or in flight. This type of component development program will allow the bearings to be tailored to the requirements of the engine.

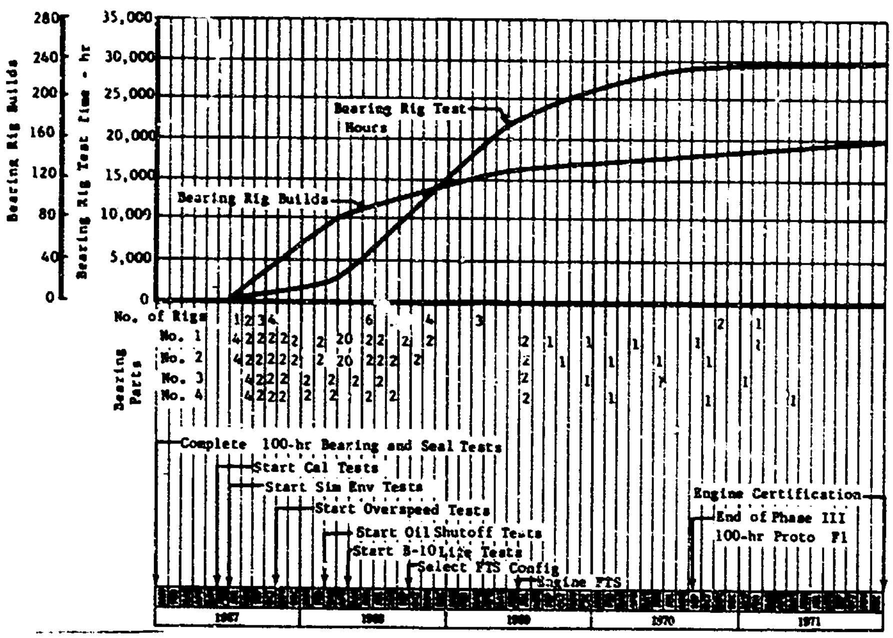


Figure 134. Bearing Rig Test Program FD 16538 EII

Program versatility will be a necessity because problems arising during the component development testing will mainly result from engine-imposed stresses and vibrations that may not be duplicated in rig testing. During Phase III, as well as Phase IV, rig testing will include duplication of engine bearing failure or bearing distress and evaluation of design modifications to establish their superiority over the previous design.

(g) Data Reduction, Analysis, and Evaluation

Reduction of bearing test rig data is straight forward because most results are directly read. Minor reduction of heat rejection data is required utilizing formula $Q = C_p \Delta T$, where Q is bearing heat generation, C_p is the specific heat at constant pressure of the test oil, and ΔT is the difference of the oil in and oil out temperatures.

The heat rejection data are then plotted as a function of load, speed, and oil flow rates. Other curves can be plotted for cage speed vs inner race speed for varying loads to define the threshold of incipient thrust bearing skidding. Plotting the data in this form allows two similar bearings to be compared with each other as well as with computer-calculated predicted bearing performance.

Evaluation of the test bearing data will determine whether the bearing has been designed properly, define bearing skid threshold, and will determine if bearing geometry changes; oil flow changes, or rotor thrust balance changes will be required.

In addition to analyzing the bearing test data, complete dimensional and visual inspection of the bearings are made at disassembly. If a bearing fails during testing or shows evidence of excessive stress during the post test inspection, a complete analysis by project engineering, design and design analytical, the Materials Laboratory and the bearing manufacturers' representatives is made to resolve the problem. Once the problem is resolved, close coordination with the vendor, often in the form of vendor plant visits, is made to expedite the corrective action.

c. Main Shaft Seal Program

(1) Background

Hydrostatic seals, in conjunction with a pressurized and vented labyrinth seal system, are used in the JTF17 engine to seal the main shaft bearing compartments. To determine the best overall seal configuration for the JTF17 engine, analytical and design studies were made on labyrinth, hydrostatic, and carbon seal designs to compare the performance, durability, and compatibility of the seal with the total engine - airframe system. This study, summarized in table 14, shows the hydrostatic seals have the lowest heat rejection, oil flow and pressurization requirements. In addition, the hydrostatic seal results in the lightest weight design with more freedom for plumbing design. With the addition of a vented labyrinth seal, this sealing system, shown in figure 135 permits the bearing compartments to be conditioned with fan discharge air comparable in temperature to the air used in today's Pratt & Whitney Aircraft commercial engines, as shown in table 15.

Each of the three main shaft bearing compartments are sealed with the same type seal configuration as described in Volume III, Report B, Section II. In operation, the hydrostatic seal floats on a cushion of fan discharge air. This pressurizing air flows through metering orifices in the contact pads into the compartment, preventing oil leakage. As shown in figure 135 a portion of the pressurizing air flows into the vent chamber where it mixes with the higher temperature engine environmental air and flows overboard through the ambient vent lines. The secondary labyrinth air seal reduces the pressure of the environmental air before

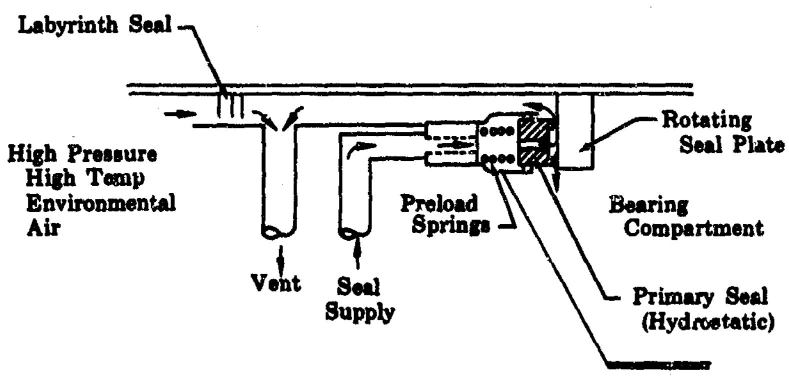


Figure 135. Schematic of Prototype Labyrinth and Hydrostatic Seal FD 16487 EII

Table 14. Comparison of Design Factors for Candidate JTF17 Rotating Shaft Seals

ITEM	CARBON SEALS	LABYRINTH SEALS	HYDROSTATIC SEALS
1. Seal heat rejection at Mach 2.7 cruise	1350 Btu/min	2200 Btu/min	350 Btu/min
2. Oil flow	145 lb/min	195 lb/min	125 lb/min
3. Maximum seal pressurization flow (% high comp air)	0.38%	0.88%	0.03%
4. Effect on heat return to airframe	Ability to meet aircraft requirement of no heat return at cruise is marginal	Cannot meet aircraft requirement	Can meet aircraft requirement
5. Effect of area-limited breather line size	No problem	Results in as much as 7 psi ΔP between compartments and gearbox on No. 3 and No. 4 bearing compartments. Could cause oil loss during rapid engine transients. Also there is no room for growth if lines have to be made larger.	No problem
6. Effect on other components	None	Will require compound main oil pump and larger scavenge pumps. Oil supply and scavenge lines would also get larger. The de-oiler would not meet minimum oil loss requirements because of speed limitations.	None

Table 15. Seal Designs and Environmental Air Temperatures

ITEM	JTF17	JT8D	JT4	JT3D	J58
Seal Type	Hydrostatic Seal with Labyrinth Backup	Labyrinth and Carbons	Carbon	Carbon	Carbon
Maximum Environmental Air Temperature	725°F	580° to 960°F	910°F	900°F	1300°F

it enters the vent chamber. This sealing system bathes the compartments with cooler air and vents any oil vapor which may escape from the compartment overboard, allowing no oil vapor to enter the cabin air bleed system. During engine start and shutdown, the preload spring forces the seal contact pads against the rotating seal plate for positive sealing of the compartment.

(2) State-of-the-Art

(a) General

Extensive experience with high speed, high temperature shaft seals has been accumulated in the development of Pratt & Whitney Aircraft's commercial and high Mach number turbojet engines. Endurance, wear, and leakage tests have been conducted in turbojet engines and in rigs. Component test results and a separate commercial airline engine seal wear rate study have established the ability of Pratt & Whitney Aircraft shaft seals to accumulate 20,000 hours or more without wearing out, with very low leakage at high speeds (24,000 ft/min), while sealing against high pressure drops (up to 300 psi) in environments up to 1300°F.

Pratt & Whitney Aircraft has been instrumental in extending the state-of-the-art for both static and dynamic seals. Basic research programs at Batelle Memorial Institute and MIT are funded by Pratt & Whitney Aircraft to study carbon wear mechanisms, dynamic seal theory, and associated studies. Pratt & Whitney Aircraft has conducted more than 66,000 hours of rig testing on actual gas turbine engine seals to extend the state-of-the-art.

Testing of hydrostatic seals has been a part of the development effort on the high altitude, Mach 3 Pratt & Whitney Aircraft J58 engine at the Florida Research and Development Center. The East Hartford plant has also conducted state-of-the-art development of hydrostatic seals with the Stein Seal Company and the Sealol Corporation. This combined development effort has resulted in a successful 150-hour J58 hydrostatic seal endurance test at conditions which simulated the J58 engine bearing compartment flight conditions with 1300°F environmental air, which is far more severe than required for the JTF17. This test and similar tests being conducted at FRDC during 1966 have verified P&WA hydrostatic seal designs.

(b) Present Phase II-C Component Status

A total of 215.2 hours of seal development testing was completed through July 1966 to verify the adequacy of the JTF17 seal designs, calibrate the seals, and to demonstrate that no detrimental interaction between the seals and bearing compartments occurred during seal operation. A total of 90 hours of this seal testing was accomplished at simulated JTF17 engine operating conditions up to Mach 2.7, 65,000 feet cruise conditions in full-scale No. 1 and 2, No. 3, and No. 4 compartment seal rigs. These compartment seal rigs consist of actual engine bearings, supports, housings, insulation, scavenge pumps, rotor hubs, and seal assemblies, including the pressurizing and venting labyrinth seals. The remaining seal tests were run in a J58 No. 2 seal rig at simulated JTF17 seal face speeds, air pressures and temperatures, and oil flows to evaluate the JTF17 seal design early in the Phase II-C program. As a result of this development rig testing and the JTF17 engine testing, including operation at Mach 2.7, 65,000 feet cruise conditions, the seal and compartment designs were verified early in the Phase II-C program.

Development testing will be conducted during Phase III to size the hydrostatic seal pressurizing orifices and balance the seals prior to engine testing. Further seal development in full-scale compartment seal rigs and in a "bladeless" engine oil system rig will be conducted during Phase III in conjunction with engine testing. After FTS, seal testing is expected to continue at a reduced rate of 1500 test hours per year to demonstrate the capability of long life and to solve problems revealed as experimental as well as those resulting from engine flight operation increases.

(3) Main Shaft Seal Development Test Program Objectives

The test objectives of the Phase III seal component development program are listed below. When feasible, testing will be accomplished in a coordinated program of engine development tests as well as in isolated component rig tests. The seal test objectives are as follows:

1. To initially verify the seal mechanical design and the analytical predictions for each of the hydrostatic seals
2. To eliminate seal oil leakage at all engine operating and static conditions
3. To ensure the seal durability is consistent with the design goal of 10,000 hour TBO by endurance testing throughout the engine flight envelope
4. To determine the ability of seals to withstand rapid thermal and pressure transients
5. To coordinate rig testing with engine testing and investigate and develop solutions for all engine seal problems
6. To evaluate and improve, if necessary, the overhaulability of the seal assemblies, evaluating seal wear limits, seal face chipping limits, and improving the ease of assembly and disassembly
7. To evaluate various seal and seal plate materials to reduce cost and increase seal life.

(4) Description of Seal Test Rigs and Facilities

(a) Seal Test Rigs

Three types of test rigs will be utilized to develop the JTF17 seals. The primary seal rig is a full-scale engine compartment test rig incorporating actual engine parts. A view of the test stand installation of a typical seal compartment rig is shown in figure 136. The rig is driven by a stand mounted, dual shaft gearbox to duplicate the speeds of the engine rotors. This rig and similar rigs for the No. 1 and 2 and the No. 3 compartments will determine the compatibility of parts in the engine compartments, the oil temperature rise across the compartments, and air temperatures and pressures throughout the vented labyrinth seals. The thermal stability characteristics of the engine lubricant at engine compartment temperature conditions, as well as seal wear and function, can be determined in these rigs.

The second type of seal rig utilized to develop the JTF17 seals is a universal hydrostatic seal rig capable of testing individual seal assemblies. A cross section of a typical rig, including the labyrinth seals, is shown in figure 137. This rig will be used to test and evaluate modifications and calibrate individual seal assemblies without assembling and testing the entire bearing compartment.

The third type of rig utilized in the development of the JTF17 seals is a "bladeless" JTF17 engine consisting of the engine bearing compartment with the associated labyrinth and hydrostatic seals, the engine lubrication system, and the engine gearboxes mounted on the engine intermediate case. Endurance tests up to 1000 hours duration will be conducted at simulated engine operating oil and air temperatures, pressures, and engine rotor speeds experienced during a typical JTF17 mission cycle. For a complete description of this rig, see the Accessory Gearbox subsection of this section.

Figure 136. JTF17 No. 4 Compartment Seal Rig Mounted in Test Stand

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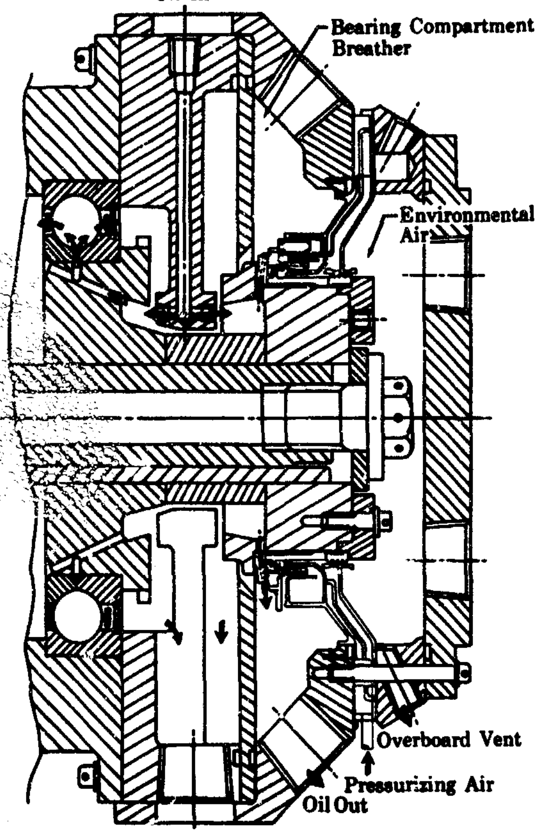

Figure 137. Universal Hydrostatic Seal Rig FD 16812 EII

(b) Seal Test Facilities

All seal rig testing will be conducted on D-1, D-3, and D-4 stands already in operation during Phase II-C. A photograph of D-1 stand drive motor, torque converter, and transmission is shown in figure 138.

Figure 138. Compartment Seal Rig Mounted in Test Stand FD 16835 EII

The JTF17 seal program test conditions will extend beyond the range of temperatures, speeds, and loads encountered in the engine. The presently available test facilities in the Area D component test laboratory are capable of supplying these required conditions. Complete details of the test facilities are contained in Volume V, Report B.

(5) Seal Component Test Programs

The following Phase III JTF17 seal development tests are planned to ensure that the program objectives are met.

(a) Seal Calibration

These are relatively short tests designed to establish seal performance characteristics. The tests will be primarily run in the universal seal rig to define the performance of the hydrostatic seals prior to engine testing. Calibration tests will also be run in the bearing compartment seal rig to measure the performance of the entire seal assembly, including the pressurizing-vented labyrinth seals. These tests will measure and evaluate air flows, temperatures and pressures at a series of speeds and air pressure levels at ambient temperatures and at elevated temperatures simulating the engine operation.

Hydrostatic seal calibration tests are scheduled for each engine seal prior to the first engine build to ensure proper engine operation. A total of forty-nine calibration tests on engine seals is scheduled through Phase III to be run in the universal seal rig. Four additional tests are scheduled for the No. 1 & 2 compartment seal rig and three each for the No. 3 and No. 4 compartment seal rig.

(b) Seal Design Modification and Material Tests

These tests determine the performance of seal design modifications and seal plate material combinations. The seal design modification could be in the form of seal spring force changes, seal face configuration changes, orifice size changes, piston ring configuration changes, or seal carrier changes. The tests will be 50-hour endurance tests at pressures and temperatures simulating those encountered throughout the engine seal operating range. The number of these tests required to develop the seals will depend upon the number of problems encountered. It is estimated that five to ten tests per seal will be required. These tests will be run in the universal seal rig.

(c) Endurance Tests

To determine the durability, compatibility, and functionability of the hydrostatic seals and the entire bearing compartment including the pressurized-vented labyrinth seals, endurance tests up to 1000 hours are planned. These tests are run in the bearing compartment seal rigs at conditions simulating a typical JTF17 engine mission cycle. The conditions include the compartment environmental air temperatures and pressures, the fan discharge seal pressurizing air temperatures and pressures, the ambient vent pressure, the compartment breather pressures, rotor speeds, bearing loads, and oil temperatures.

A total of 6600 hours of endurance testing is planned for the three compartment seal rigs during Phase III. These endurance tests will include three 150 hour tests, one 500 hour test and one 1000 hour test per compartment and are scheduled to start after the seal calibration and design modification tests have indicated that the seal configuration operates properly.

The general scope of the seal program is to conduct performance and durability tests on the various seal designs until all JTF17 engine goals have been achieved. The scheduling of seal testing has been arranged so that the basic design features of each seal can be confirmed by calibration tests. As shown on figure 139, this will be accomplished 17 months after the start of the program, at which time 1000 hour endurance tests will start. Material and seal design modification testing will be completed at least six months prior to JTF17 engine FTS. This will allow the seal durability to be established and provide the engine with the optimum rig-developed seal for each engine seal position. After FTS, seal testing is expected to continue at a rate of approximately 1500 seal test hours per year. This testing will be conducted, as required, to eliminate problems encountered in experimental and production engine operation. The end result will be to extend the life of each seal so that a 10,000-hour JTF17 engine TBO can be eventually achieved.

The overall test hours per seal position, and the number of tests on each seal during Phase III is shown in Table 16. The total seal test time of 13,000 hours is also tabulated into the number of hours per seal for the three types of tests required to develop the seals. Figure 139 shows the number and rate of test hours to be accumulated during Phase III and through Phase IV. The number of rig hours in figure 139 differs from the number of seal development hours in table 16 because the No. 1 and 2 bearing

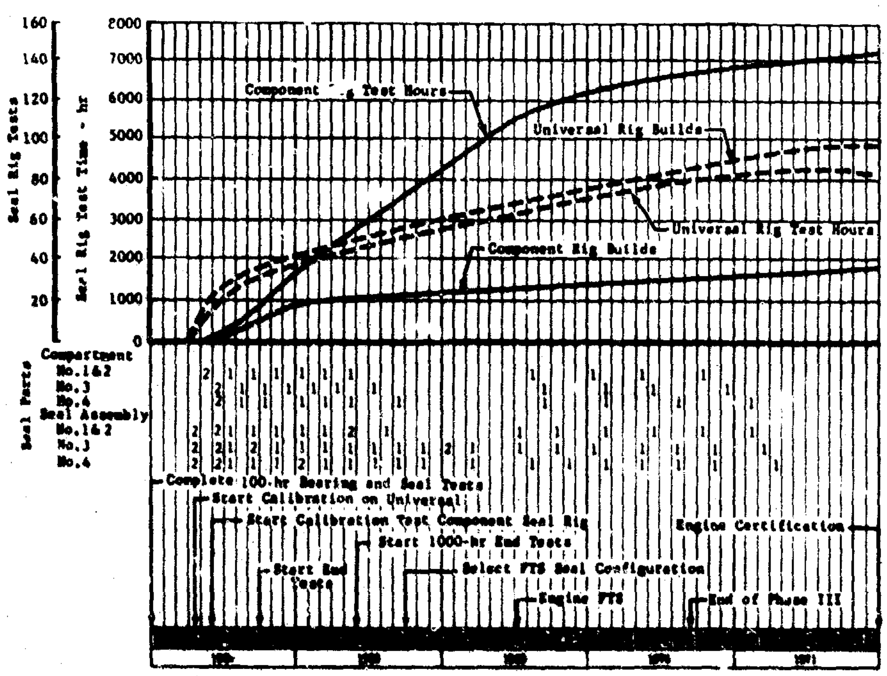

Figure 139. Seal Rig Test Program FD 16539 EII

compartment seal rig tests the No. 1 front, No. 1 rear and No. 2 front, and the No. 2 rear during one test in the one rig. Figure 139 also shows the JTF17 milestones, the number of seal and bearing compartment parts required and the rate of rig builds.

Table 16. JTF17A-21 Seal Test Program

Test Description	No. 1 Front Seal		No. 1 Rr. & No. 2 Front Seal		No. 2 Rear Seal		No. 3 Front & Rear Seal		No. 4 Seal	
	Test No.	Test Hrs.	Test No.	Test Hrs.	Test No.	Test Hrs.	Test No.	Test Hrs.	Test No.	Test Hrs.
Seal Calibration in Universal Rigs	1-7	300	1-7	300	1-7	300	1-7	300	1-7	300
Seal Calibration in Compartment Seal Rigs	8-11	200	8-11	200	8-11	200	8-10	200	8-10	200
Seal Design Modification Tests	12-16	250	12-16	250	12-18	350	11-20	500	11-18	400
Simulated Environmental Endurance Tests	17-21	1750	17-21	1750	19-23	1750	21-25	1750	19-23	1750
		2,500		2,500		2,600		2,750		2,650

(d) Data Analysis and Evaluation

All data obtained from the shaft seal test program, such as before and after physical material dimensions, seal airflow measurements, rotor speeds, pressurizing and vented air temperatures, and pressures, will be correlated and evaluated to aid in the selection of the optimum seal configuration for each location.

To evaluate the data, the leakage rates and temperature levels are plotted as functions of speed and air pressure. This type of performance curve permits direct comparison with other seals and with analytical predictions.

Seal measurements before and after tests are made to determine wear rates for various seal designs and material combinations.

Seal performance and wear levels will be evaluated to determine that they are commensurate with engine seal wear and breather flow rate requirements.

d. Accessory Gearboxes

(1) Background

A gear and shaft drive system is provided in the JTF17 intermediate case to extract airframe and engine accessory power from, and supply starting torque to, the engine high compressor rotor. The power required is transferred through sets of spiral bevel gears in the engine intermediate case through radial "towershafts" to three accessory gearboxes located on the outside of the intermediate case. The three gearboxes are (1) engine main accessory drive, (2) engine secondary accessory drive, and (3) airframe accessory and starting gearbox drive (PTO).

The design of the engine main accessory gearbox is common to both Lockheed and Boeing airframes. This gearbox provides drive capability for the gas generator fuel pump, the engine hydraulic pump, the engine unitized fuel control, the N_2 tachometer, and the lubrication system de-oiler.

The engine secondary accessory gearbox is different for the Boeing and Lockheed installations. In the Boeing installation, this gearbox contains the oil pressure pump, oil filter, oil pressure regulating valve, No. 1 and No. 2 bearing compartment scavenge pump, and the No. 3 bearing compartment scavenge pump. In the Lockheed installation, this gearbox is the same with the added requirement for supporting and driving an air compressor component of the airframe air-conditioning system.

The power takeoff (PTO) gearbox for both the Boeing and Lockheed installations provides drive capabilities for the airframe accessories and is used to supply starting torque to the engine. The PTO gearbox provided for the Boeing Company installation has provisions for supporting and driving two airframe hydraulic pumps and an airframe accessory drive. The PTO gearbox for the Lockheed California Company installation includes provision for coupling to an airframe-furnished flexible shaft and a remotely actuated decoupler.

All production JTF17 gearbox housings are titanium castings. This material provides the best strength-to-weight ratio at the gearbox operating temperatures and takes maximum advantage of the lower cost of cast construction. While the technique of casting titanium is being developed, fabricated titanium gearboxes, similar to those used successfully on the J58 engine, will be developed for the JTF17 prototype engine during Phase III.

Accessory gearboxes used on P&WA gas turbine engines have demonstrated long life and high levels of reliability. This experience is employed in the design of the JTF17 gearboxes. This section of the JTF17 proposal describes the Phase III accessory gearbox development test program planned to ensure that gearboxes are reliable, maintainable, and durable enough to meet the requirements of the JTF17 engine.

(2) Phase II-C Status

During Phase II-C, the J58 engine gearbox was modified to duplicate the JTF17 method of mounting the main accessory gearbox to the inter-

mediate case and of scavenging the oil from the No. 1 and 2 bearing compartment. There was no undue gearbox vibration. Compartment scavenging was inadequate early in Phase II-C, but was corrected by simple reoperations to increase drain areas. The experience gained will be utilized in Phase III.

Investigation was initiated during Phase II-C to evaluate the feasibility of cast titanium gearboxes. Samples of cast titanium housings have been made as shown in figure 140. During Phase III, this development will continue to be directed toward production of low cost high quality cast titanium gearboxes for the JTF17 production engine. Fabricated titanium gearboxes will be used for prototype engines unless casting techniques improve at a rate which justifies their incorporation. For additional information on the Phase III development of titanium castings, see Analysis of Specified and Proposed Materials in Volume III, Report F, Section II.

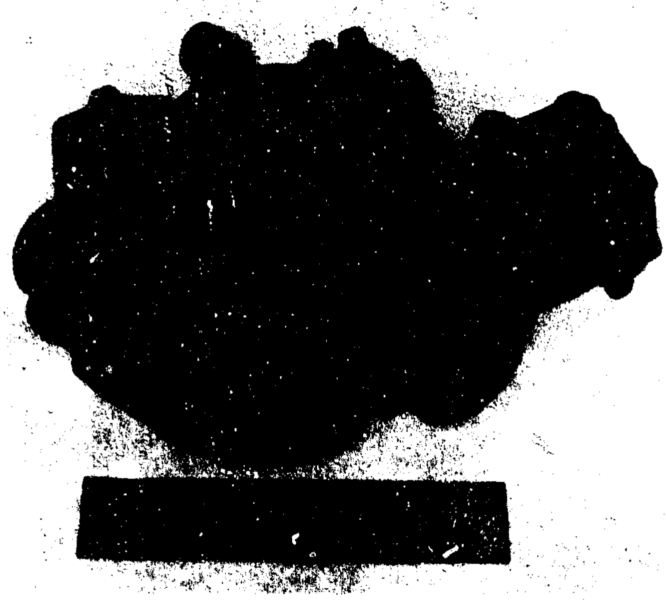

Figure 140. Titanium Casting FE 61376 EII

(3) Gearbox Development Test Program Objectives

A primary objective of the accessory gearbox component test program will be to investigate gearbox performance and durability over the entire range of engine and airframe operating conditions. Tests at environmental conditions simulating those anticipated in flight will serve four purposes:

1. To verify the soundness of the initial designs.
2. To search out and correct problems resulting from the flight environment before they are encountered in actual flight.

3. To develop test facilities and techniques capable of simulating flight conditions so that, in the event that new problems are encountered during flight test, the equipment to aid in correcting these problems will be ready.
4. Provide test experience to facilitate future growth.

Engine and rig testing of the accessory gearboxes and towershafts will be required to develop and verify the adequacy of the cast titanium gearboxes to satisfy the airframe and JTF17 requirements for engine power extraction, reliability, maintainability, overhaulability, and compatibility with other subsystems, and of meeting FTS requirements. The test rigs and facilities and the proposed Phase III programs are described in the following sections.

(4) Description of Gearbox Test Rigs and Test Facilities

A continuing gearbox development program has been conducted by P&WA to ensure that gearboxes are reliable and durable enough to meet advanced engine needs. Figures 141 and 142 show a full-scale J58 gearbox rig mounted on an engine diffuser case and driven by a high horsepower motor. The gearbox drives are loaded and the entire unit shrouded for simulation of actual engine operating conditions. This test stand will be modified early in Phase III to accommodate a "bladeless" JTF17 engine so that all the JTF17 gearboxes, towershafts and drive gearing can be tested at the same time at simulated engine operational conditions. The only nonstandard engine parts required will be adapters necessary to mount the rig to provide the necessary external drive.

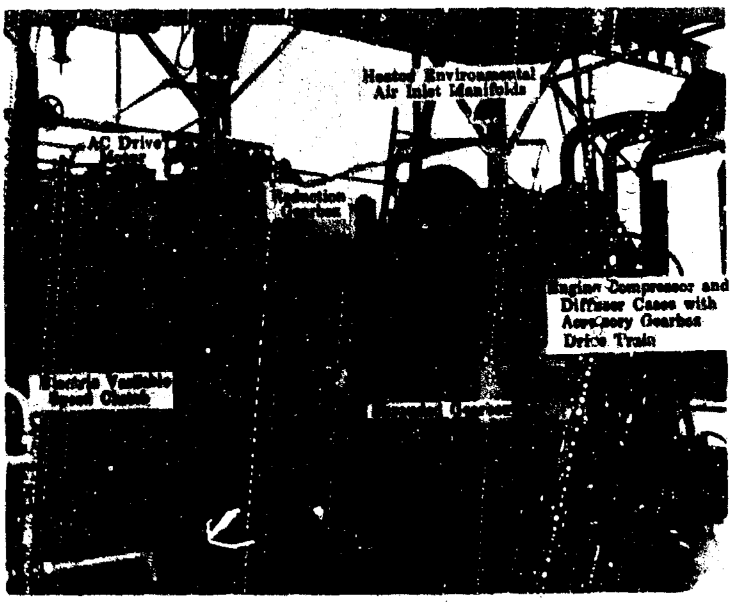

Figure 141. Full-Scale J58 Gearbox Rig (Shrouded)

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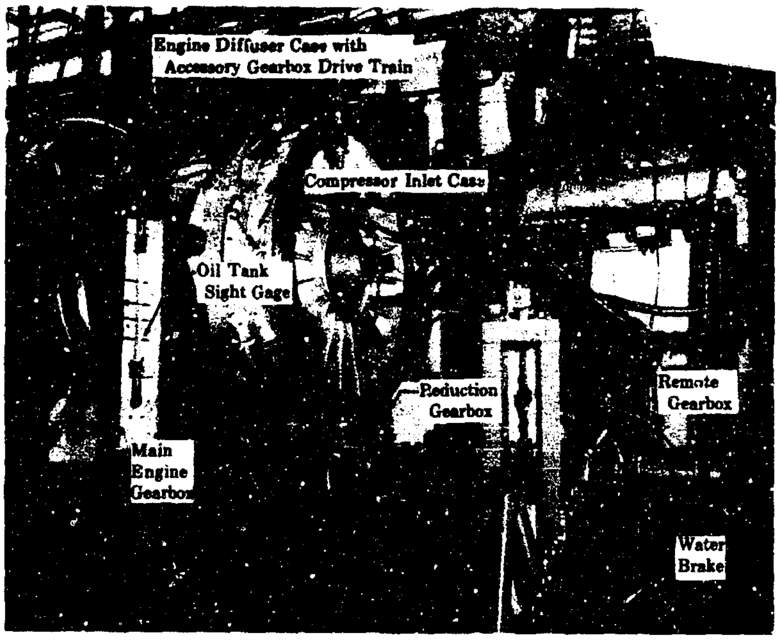

Figure 142. Full-Scale J58 Gearbox Rig (Unshrouded) FD 16836 EII

To test the individual gearboxes, existing test stands similar to the one shown in figure 143 will be modified to accommodate the JTF17 accessory gearboxes. These test stands are capable of supplying the rig oil flow and drive power, simulating the engine environmental air pressure and temperatures, and supplying water brakes to load the gearbox accessory drive pads.

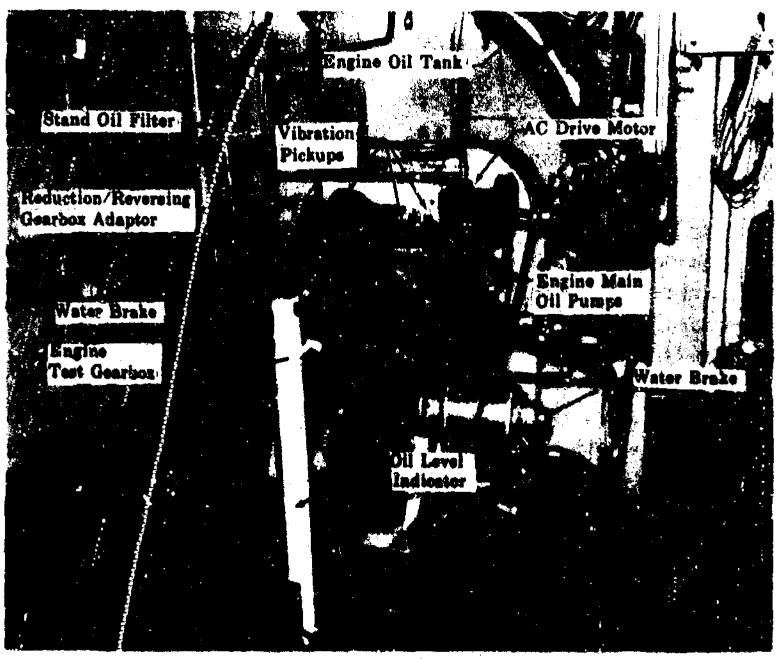

Figure 143. Typical Engine Gearbox Mounted in Test Stand FD 16833 EII

(5) Gearbox Test Programs

The objectives of the JTF17 accessory gearbox program will be met by testing separately the accessory gearboxes fully loaded and unloaded in high temperature and sea level ambient temperature environmental conditions. All the gearboxes will also be tested together on the "bladeless" JTF17 engine at loaded and shrouded conditions for simulation of actual engine operation. Additional testing will be accomplished in the Materials Laboratory and on the JTF17 development engines.

A total of 8200 hours of accessory gearbox calibration and endurance tests is planned for the three accessory gearboxes. These tests will be conducted in the individual gearbox test stands. The test gearbox will be instrumented to determine seal and bearing temperatures, housing stress levels, and vibration levels. Dummy weights and torque loads duplicating maximum accessory loads will be applied during these tests. Overload torques will be applied during this program as required to simulate the aircraft and engine accessory requirements. Careful inspection of the detail parts and measurement of the wear incurred after each test, as well as analysis of the data obtained, will provide the information necessary for the redesign and correction of discrepant items.

In addition, subassemblies within the gearbox assembly will be run to develop and verify satisfactory operation. For example, the oil jets will be calibrated to verify correct jet flow, flow pattern, and direction; the air-oil separator (deoiler) will be tested to verify satisfactory deoiling capability; the breather-pressurizing valve will be run to set and verify its opening and closing capability; individual gear blanks will be "rung" to verify the absence of detrimental resonances in the engine operating speed range, the gears will be tracked and checked to ensure proper engagement and back-lash; seal travel adequacy will be checked; and housing pressure and leak tests will be conducted.

Also, a resonant vibration test will be conducted in the Materials Laboratory with the gearbox assembly attached to the intermediate case to ensure that no detrimental resonances are present within the engine operating range.

In addition to the 8200 hours of individual gearbox testing explained above, 7100 hours of endurance testing will be accomplished in the oil system and gearbox test rig (bladeless engine) to develop the engine accessory gearbox drive spiral bevel gears; the towershaft bearings, seals, and shafts; and the three engine gearboxes mounted on the engine intermediate case. These endurance tests, up to 1000 hours duration, will be conducted as simulated operating temperature, pressures, speeds, and gearbox drive pad loads simulating those experienced during a typical JTF17 mission cycle. Special 100-hour endurance tests will be run to evaluate repaired gearbox housings and bearing supports to evaluate the overhaulability of the gearboxes. With the gearboxes mounted on the "bladeless" engine gearbox rig and the airframe/engine nacelle simulated, gearbox maintainability tests will be conducted to ensure ease of maintenance checks and servicing of the gearboxes. The gearboxes and towershaft assembly will be instrumented to record the vibration levels; oil temperatures; breather pressures, temperatures, and flows; and gearbox metal

temperatures. These endurance tests will determine the adequacy and service limits of the seals, gears, bearings, oil flow rates, and housing structure and the respective component function characteristics, i.e., oil pump capacity, seal wear rate, and gear wear stress levels.

(6) Test Results

Gearbox test results in the form of temperature data, seal wear rate, and stress data will be reviewed following each test. Also, operational results will be reviewed; and visual, dimensional, and material inspections will be conducted. Performance of each of the subsystems and components in the gearbox will also be evaluated. As deviations or discrepancies are observed, continuing development tests will be conducted as redesigns are made and the modified parts are incorporated in the gearbox assembly. Initially, satisfactory temperature and stress levels measured on previous engine model gearbox assemblies will be utilized as a standard of acceptability until actual JTF17 tests provide more accurate and specific information.

(7) Component Test Schedules

A total of 14,900 hours of gearbox rig testing is proposed during Phase III to develop gearboxes for the JTF17 production engine. During the early stages of Phase III, fabricated titanium gearboxes will be rig tested and developed for engine use while cast titanium gearboxes are being developed for the production engines. An estimated five sets of fabricated main accessory gearboxes and secondary gearboxes will be required for rig development during Phase III. An estimated eight sets each of the cast titanium main, secondary, and PTO gearboxes will be required during Phase III to conduct tests of the cast titanium gearboxes directed toward Type Certification tests. The planned schedule of rig builds milestones, gearbox test hours, and parts procurement during Phase III is shown in figure 144. The estimated gearbox testing after FTS to correct and evaluate any new problems encountered during flight testing is also shown in figure 144 as 5700 hours up to Engine Certification.

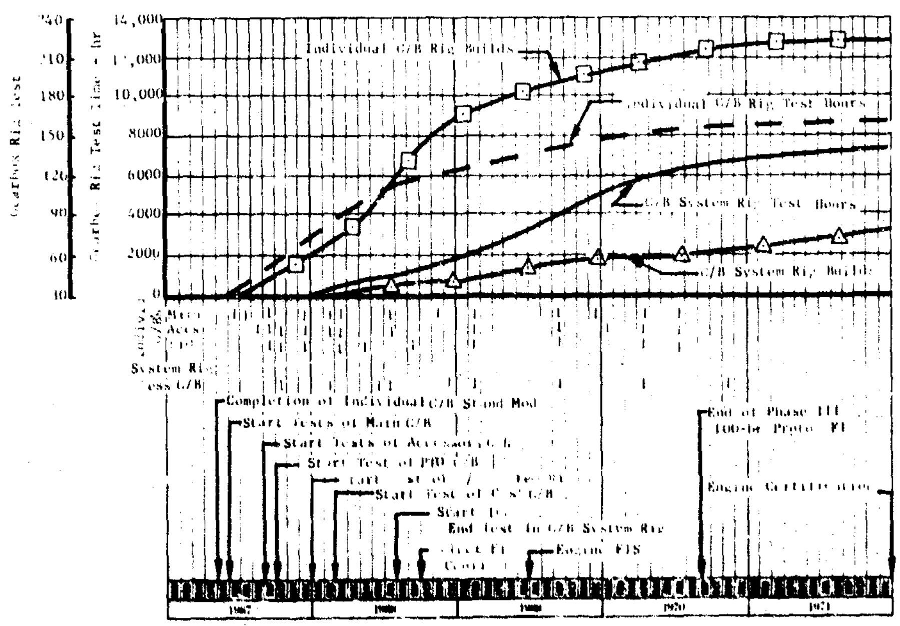

Figure 144. Gearbox Test Program FD 16801

C. CONTROLS AND ACCESSORIES

1. Engine Control System - General

The JTF17 engine control system, which is described in detail in Volume III, Report B, Section III, must have a high degree of reliabili durability, and accuracy as well as provide serviceability and maintainability. An intensive program of development testing and design refinement will be conducted to ensure that the system and components meet these requirements and to investigate and correct problems as they may develop during the bench, engine, and flight test programs.

The component development test plan for the major control system components is based on over 15 years of P&WA experience in development of turbine engine components. This experience includes the development of the control components for the great majority of the turbine engines in commercial use today, as well as the development of the components for the supersonic P&WA J58 and TF30 military engines.

The component testing planned for the JTF17 control system will follow a well-established plan starting with design support tests, such as material and seal tests, while the individual control system units are being designed. This will be followed by subassembly bench tests; complete unit bench tests; pump and control system bench tests; engine tests, including tests with a simulated aircraft fuel system; and aircraft inlet and engine wind tunnel tests and flight tests to confirm that the engine control and the aircraft inlet control systems are compatible. Both bench and engine tests include a high percentage of performance and endurance testing at simulated SST mission cycle conditions including high fuel and ambient air temperatures. J58 engine experience has shown that this type of component development test program is required to define problem areas and substantiate the modifications required to correct the problems so that the production units will meet the design performance, durability and reliability goals. This work will also be used as a basis for establishing the acceptance test requirements for production components.

A detailed description of the development test plan, and test schedule for the major fuel and control system components, including the following are included in the following sections of this Component Test and Certification Plan.

1. Unitized fuel and area control
2. Gas generator fuel pump
3. Duct heater fuel pump
4. Hydraulic fuel pump
5. Fuel manifold drain valves
6. Ignition system
7. Engine pressure ratio control

The development plan for the components of the JTF17 engine control system will include a series of major performance and endurance demonstration tests which are as follows.

a. 75-Hour Hot Mission Cycle Component Bench Test

(1) Objective

The objective of this test is to establish the durability of the component for engine endurance tests.

(2) Details of Test

The test consists of subjecting the component to a mission test cycle which simulates the fuel temperatures, ambient air temperatures, and engine operating conditions on a typical mission.

A typical mission cycle, which covers a three-hour time period, is illustrated in figure 145 and is as follows: Twenty-five minutes at a constant component inlet fuel temperature of 140°F while ambient temperature is held to a constant 100°F. This period simulates the taxi, climb to 5000 ft., hold at 5000 ft. and beginning of climb to cruise. The remainder of the climb to cruise altitude and Mach number is simulated by an increase in fuel temperature from 140°F at 25 minutes to 200°F at 45 minutes, while ambient temperature remains at 100°F to 36 minutes and then increases to 600°F at 45 minutes. Aircraft cruise is simulated by holding ambient temperature constant, to 159 minutes, at 600°F and increasing fuel temperature, linearly with time, to 255°F at 160 minutes. Aircraft descent is simulated by decreasing ambient temperature to 100°F at 165 minutes and decreasing fuel temperature to 140°F at 177 minutes. The remaining landing and taxi maneuvers are simulated by holding fuel and ambient temperatures constant. The component operating conditions are modulated to simulate engine operating requirements throughout the test. Twenty-five cycles will make up the 75 hours of testing.

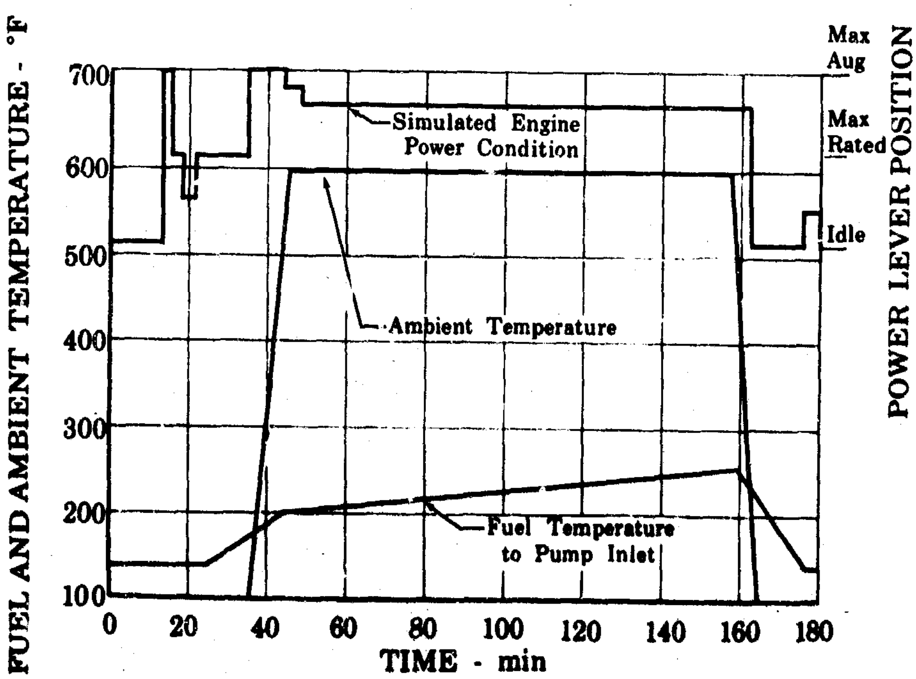

Figure 145. Typical Mission Cycle

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The rate of change and abolute levels of fuel and ambient temperature are based upon a typical flight mission and may be modified slightly to match bench capabilities.

Calibrations at sea level standard environment temperature and fuel temperature will be made prior to and after the 75-hour test.

b. Arnold Engineering Development Center Tests

(1) Objective

The object of this test series will be to evaluate the overall aircraft and engine system to determine if any problems exist in the engine control system when run as part of the propulsion system and thereby permit any necessary corrective action to be taken at the earliest possible opportunity. This program will establish the compatibility of the engine control system with the aircraft induction control system.

(2) Details of Test

A detailed description of this test is included in Volume III, Report D, Section II.

c. 75-Hour Flight Test Status Test

(1) Objective

The complete fuel and control system will be installed on the JTF17 engine which will be subjected to the FTS test. Satisfactory completion of this test will establish the parts lists for the system components for use on prototype JTF17 engines.

(2) Details of Test

A detailed description of this test is included in Section IV of this report.

d. 100 Hours of Flight Testing

(1) Objective

The objective of this test series will be to test the complete fuel and control system in the ultimate environment and confirm that the engine control system is compatible with the aircraft inlet system.

(2) Details of Test

A detailed description of this test is included in Section V of this report.

e. 550-Hour Component Bench Test Including Hot Mission Cycle and Contaminated Fuel Testing

(1) Objective

This test will confirm the design of the components is satisfactory for operation throughout the JTF17 engine envelope and to establish the durability of the components for engine endurance tests.

(2) Details of Test

A 550-hour bench test will be conducted during Phase IV and will include cycles with hot and cold fuel, hot and cold ambient, and performance tests. A component calibration will be made and will include, where applicable, additional adequate subsystem data to evaluate the performance of each critical subsystem. When the initial calibration has been completed, the component will be placed dry in an air oven and maintained at an ambient temperature of approximately 200°F for a period of 168 hours.

Upon completion of the accelerated aging cycle, tests will begin which simulate a flight mission including the extremes of the flight envelope. Throughout the mission cycle testing, data will be recorded for component evaluation. Mission cycle testing will accumulate 150 hours. Upon completion of the mission cycle testing, the component will be completely disassembled for examination of all parts. Critical measurements will be taken to disclose possible worn or distorted parts.

The component will be reassembled and calibrated. Upon completion of the calibration the mission cycle endurance testing will be continued for an additional 150 hours. Following this, the unit will be run for thirty minutes at sea level takeoff conditions. At the end of thirty minutes, a one-pint slug of salt water in accordance with specification QQ-M-151A-4 will be introduced into the component. After introduction of the salt water, the test condition will be resumed and continue for twenty minutes. The test will be stopped and the test set-up allowed to remain idle for seventy-two hours with the component remaining full of fuel for this time. Upon completion of the salt water test, the unit will undergo functional cycling for at least 145 hours. After 65 hours of cycling, eight grams per 1000 gallons of contaminant per MIL-E-5007A will be added to the fuel supply tank and cycle testing continued. At the end of 135 hours, all full-flow filters will be removed and ten hours of testing performed with fuel contaminated as above.

Upon completion of the contaminated tests at room temperature, the component will be soaked in a -65°F ambient for 20 hours. After cold soak, 20 simulated starts will be made. Each start will be made with a fuel temperature corresponding to 12 centistokes and followed by approximately one hour of functional cycling. Maximum fuel temperature allowable during the cycling test is -20°F. The component will then be tested for a period of 75 hours at the maximum fuel and ambient temperature conditions. The 550 hours will be completed by various tests which are applicable to the particular type of component. Examples of this are high bypass flow conditions for the gas generator fuel pump and the unitized fuel control and low inlet pressure tests for the gas generator and duct heater fuel pumps.

f. 150-Hour Engine Type Certification Test

(1) Objective

The complete fuel and control system will be installed on the JTF17 engine which will be subjected to the 150-hour engine type certification test. Satisfactory completion of this test, to be conducted during Phase IV, will establish the parts lists for the control system components for use on production JTF17 engines.

(2) Details of Test

A detailed description of this test is included in Section VI of this report.

g. 5000-Hour Component Bench Endurance Test

(1) Objective

The object of this test, which is to be conducted in Phase IV, is to determine on an accelerated basis the durability capabilities of the major control components.

(2) Details of Test

The test will consist of 5000 hours of cycle testing with room temperature ambient conditions and 250°F fuel temperature. Performance data will be recorded throughout the test to ensure proper component operation. The component will be disassembled and a detail inspection made of critical parts upon completion of the 5000-hour endurance test.

h. 150-Hour Component Bench Quality Assurance Tests

(1) Objective

The object of these tests is to assure that the quality necessary for satisfactory component performance under extreme environmental conditions is being maintained on production components. Refer to Volume IV, Report F, Section III for description of P&WA vendor quality assurance controls.

(2) Details of Test

Out of each order for delivery of components, at P&WA option, one unit out of each lot of 50 for the first 250 delivery units and one unit out of each lot of 100 delivery units for all remaining deliveries, selected at random by P&WA, may be subjected to a 150-hour hot bench mission cycle endurance test using the cycle as defined in figure 145.

The bench test programs will be defined by P&WA and will be accomplished both by the vendor and by P&WA as directed by P&WA Engineering. Engine and system testing will be accomplished by P&WA. Tunnel and flight tests will be coordinated programs with P&WA, FAA, and the airframe contractor.

Development engine testing during the early part of Phase III will be supported by the utilization of modified J58 and TF30 engine fuel and control system components, the same as those used satisfactorily in the Phase II-C engine test program. These components provide the versatility required during early engine testing, permit early evaluation of the proposed JTF17 control mode and provide engine endurance time on the same type hardware as will be used in the prototype control system components. Additional sets of these interim control components will be procured to maintain an uninterrupted engine test program until the prototype components are available at P&WA and have been thoroughly bench tested. The procurement schedule for additional sets of experimental engine type control system components, and the bench and engine test time estimated for these components are shown in figure 146. These components are described in more detail in Report B, Section III. The JTF17 engine test experience accumulated during the Phase II-C program as well as the results of final engine sizing and installation coordination with the airframe manufacturer will be incorporated into the prototype control component designs prior to release for fabrication.

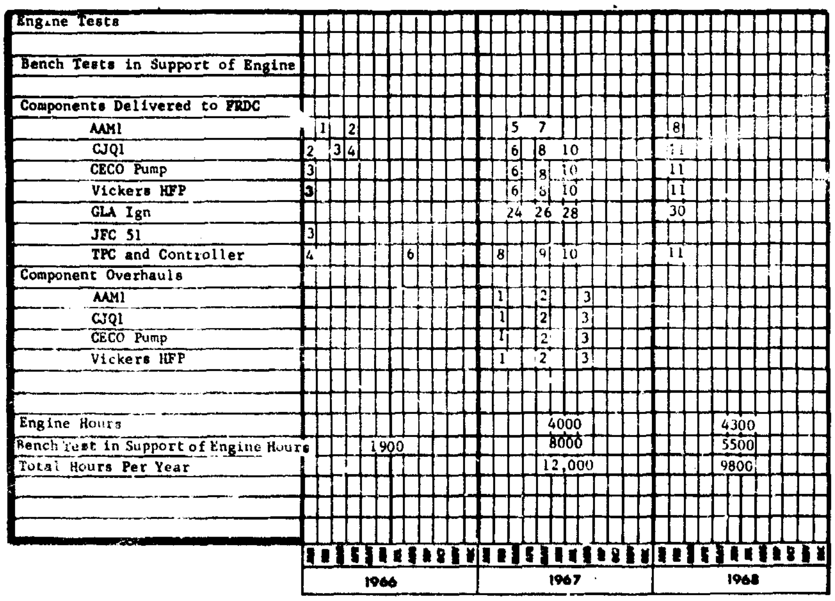

Figure 146. Initial Experimental Engine Type Control System Components Development Test Schedule — FD 16488 EII

To assist in the establishment of fuel and control system schedules to match the engine component characteristics and engine dynamics in the most economical and efficient manner, a special control mode engine test and development tool, called the Digital Electronic Breadboard (DEBB), has been developed and will be used in the JTF17 engine control development program as required. This system permits rapid variation or adjustment of control system schedules or modes and provides for quick evaluation of the effect of these variables on overall engine-control system performance.

DEBB includes a general purpose digital computer plus input and output devices having the versatility to produce a wide range of control schedules simulating a variety of scheduling modes. The control is capable of reading 40 engine parameters by equipping the engine system with suitable sensing devices such as flowmeters, pressure sensors, temperature transducers, and similar items.

The schedule computations are performed by a digital electronic computer and related signal conditioning equipment. The basic computer and related equipment are mounted in a trailer for mobility. All of the sensed signals will be conditioned, scanned, then read into the computer memory. Computation of schedule points and control signals will be interspaced with data scanning, and the entire acquisition and computation cycle will be completed in 10 milliseconds. The predetermined flow schedules and closed loop operating conditions will be fed into the computer by means of punched paper tapes. It will be possible to change individual points on these schedules through a typewriter input to provide immediate on-the-spot schedule flexibility. Also, it will be possible to switch the engine from the automatic control mode to a manual control panel to allow surveying special interest areas.

The computer controls the outputs to the engine which are applied through electrically piloted hydraulic packages incorporating the necessary filters, throttling valves, shutoff valves, actuators and similar components to control engine fuel flows, duct exhaust nozzle actuator positions and auxiliary functions.

The DEBB system will be very useful in isolating and investigating any problems that might arise within the JTF17 control system. It is possible to select and control only the parameters which are desired when utilizing the system for trouble shooting. For instance, should the duct nozzle system not have the desired stability, the DEBB system can be utilized to control this particular parameter and various system gains and phase lags could be readily tested to determine what would be required to correct the problem prior to any hardware changes. This approach can substantially shorten engine test programs and thus reduce costs.

The DEBB system, as shown in figure 146A, will be delivered to FRDC in August 1966 for initial checkout on a J58 engine after which the unit will be available for use in the JTF17 program as required.

2. Unitized Fuel and Area Control

a. Introduction

(1) Background

The unitized fuel and area control is a hydromechanical unit and is described in detail in Volume III, Report B, Section III. The control schedules gas generator and duct heater fuel flows, regulates the duct heater exhaust nozzle area to control total engine airflow, schedules actuation of the compressor inlet guide vanes and compressor bleeds, schedules the positioning of the reverser-suppressor for forward or reverse thrust and controls the speed of the duct heater fuel pump.

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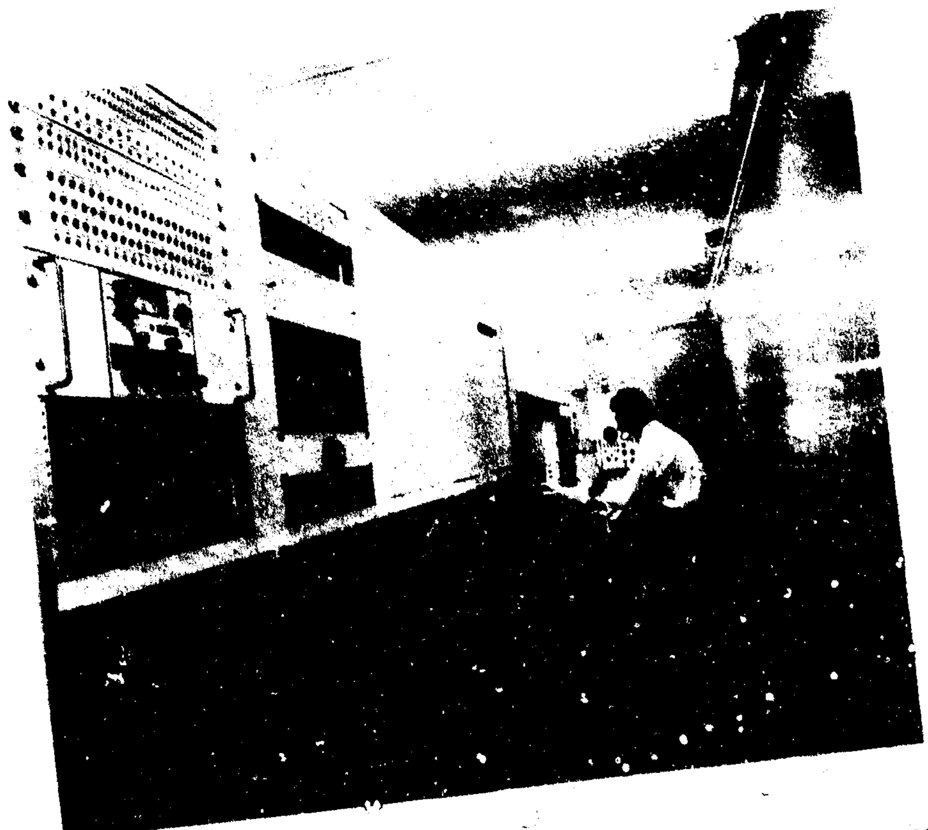

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Figure 146A. Portable Digital Electronic Breadboard Control System (DEBB)

The overall function of the unitized fuel and area control is to control the engine within acceptable operating limits during all phases of engine operation from start to shutdown and throughout the engine operating envelope. This control is of the same basic design and uses the same operating principles as the hydromechanical fuel controls used on current Pratt & Whitney Aircraft engines such as the JT3, JT3D, JT4, JT8, JT8D, and J58.

The Test and Certification Plan for the unitized fuel and area control described herein includes the current status of the control, the objectives of the plan, a description of the test equipment to be used for conducting the plan, descriptions of test programs planned for the control, and an overall test schedule.

(2) State-of-the-Art

(a) General

Current day technology for turbine engine hydromechanical control system components is capable of producing a unitized fuel and area control for the JTF17 engine. Aircraft powered by the Pratt & Whitney Aircraft J58 engine are currently operating on a daily basis at environmental conditions which are more extreme than the conditions which will be encountered in the supersonic transport application.

The development program for the unitized control will be conducted in the same manner and in many instances by the same personnel who were directly responsible for the J58 program. Current control technology has also proven that durability and reliability characteristics have reached the point which permits 8000 hours time between overhaul for hydromechanical fuel controls. This goal has been obtained by a model of the JFC-25 fuel control used on the Pratt & Whitney Aircraft JT3D engine. The development of this control was a joint effort of Pratt & Whitney Aircraft and the control vendor, Hamilton Standard Division, with direction of the program being provided by Pratt & Whitney Aircraft.

(b) Phase II-C Component Status

Considerable preliminary design work on the unitized fuel and area control has been completed by both Hamilton Standard and Bendix, the two candidate vendors being evaluated during Phase II-C. The work has defined the location of the major pistons, valves, and servos, the computing linkage and the external installation configuration. The design of the control will be completed early in Phase III. Selection of the vendor for the control will be made during Phase II-C.

The basic design concepts used in the unitized fuel and area control were selected because of the consistently good results obtained with this type of control on current engine models. Maximum use of the experience accumulated by the control vendors and Pratt & Whitney Aircraft from both commercial airline applications and high Mach number applications will be utilized.

The test program for the unitized fuel and area control was initiated during the Phase I portion of the SST program and has continued throughout

the Phase II program to date. Testing has consisted of tests at the vendors' plants to establish basic concepts, evaluate seal designs and materials at elevated temperatures, and investigate housing casting material properties. In addition, data obtained from the Phase II-C engine test program to date are being used to establish the required control schedules and input parameters. These data and extensive computer studies are being used as part of the basis for the control system design. At the end of Phase II-C, one of the two candidate vendors will be selected to develop the unitized fuel and area control during Phase III.

b. Test and Certification Plan Objectives

The basic objective of the Test and Certification Plan is to qualify the JTF17 unitized fuel and area control for use on prototype and production engines, to establish compatibility of the engine control system and the airframe air induction control system, and to develop the control to the degree of accuracy, reliability, and maintainability required for service use on the supersonic transport aircraft.

To accomplish this, the programs presented for the component major performance and endurance demonstration tests described in the previous section will be conducted as well as the following programs which are specifically for the unitized fuel and area control:

(1) Component Rig Tests

Component rig tests will be conducted to determine the accuracy, stability, durability and response of various control subassemblies and where necessary prove that corrective action taken on the component provides the desired performance and durability.

(2) Development Bench Tests

The objective of these tests will be to confirm that overall control performance relative to accuracy, stability, response, and durability is acceptable, and undesirable interactions between control subassemblies are not encountered. Particular emphasis will be placed on hot fuel and hot ambient air tests.

(3) Engine Tests

Tests conducted on the unitized control in conjunction with and part of the overall engine program will be a continuation of the bench tests of the control to confirm the unit is compatible with other components of the various systems and to show that the unit has the desired accuracy of output functions and durability, particularly on endurance and simulated high Mach number-altitude engine test programs.

(4) Electronic Hardware Tests

Evaluation tests will be conducted on the digital electronic airflow control module for comparison with similar tests to be conducted on the hydromechanical airflow control module, these tests emphasizing accuracy, reliability, and durability.

c. Unitized Fuel and Area Control Test Facilities

J58 experience has emphasized the importance of testing the fuel system components in an environment which simulates actual flight conditions. The Florida Research and Development Center turbine engine component test facilities are thus oriented toward high temperature fuel and ambient air testing. The major portion of the test facilities which were used in the successful development of the J58 engine control system components will be used in the development program on the JTF17 unitized fuel and area control. The following is a tabulation of some of the benches to be used to test the unitized fuel and area control.

Test Stand Number	Type of Test to be Run
D-9	Calibration Tests
D-13	Calibration Tests
D-11	Hot Fuel, Calibration and Room Temperature Ambient Endurance
D-12	Hot Fuel, Calibration and Subassembly Dev.
D-18	Calibration and Dynamic Response Tests
D-7	Complete System Development and Heated Fuel and Ambient Endurance.

Two additional electronic control stands are required to support the program, each capable of calibrating, reprograming, and maintaining the digital electronic airflow computer by simulating inputs, measuring outputs, simulating output loads, and accomplishing trouble shooting.

Another very important facet of bench testing is to simulate the other components in the system and thus experience any interactions that might be encountered during engine operation. The test benches incorporate suitable electric motors and air supplies to drive the actual engine pumps to supply fuel to the unitized control and loading devices to simulate the duct nozzle actuator loads during duct nozzle control tests. One test bench at the Florida Research and Development Center can be used to test the complete fuel and hydraulic system. An electric drive is incorporated on this bench to drive the engine gearbox; the components are then mounted to the engine cases, and engine plumbing is used. This bench also has the capability of operating with fuel temperature up to 300°F at the pump inlet. Individual insulated chambers can be installed to operate the components in an inert ambient atmosphere up to 1200°F. Figure 147 shows this bench in operation with J58 components.

d. Component Test Programs

The test program planned for the JTF17 unitized fuel and area control is presented in figure 148. As shown on this chart, a total of 81,700 hour of bench testing at Pratt & Whitney Aircraft and the vendor's facility are planned through Phase III, and [illegible]1,400 additional hours in Phase IV. 9160 of the hours of bench testing scheduled during Phase III will be at elevated temperatures and the remainder at room temperature conditions. 8185 of the test hours scheduled to be conducted during

Phase IV will be at elevated temperatures. The number of bench test hours scheduled to be conducted at elevated temperature conditions is based on history accumulated during the J58 program which indicated that a minimum of 12 percent of the total bench test time must be conducted at simulated high Mach number flight conditions in order to properly detect, investigate, and correct problems associated with this type of operation.

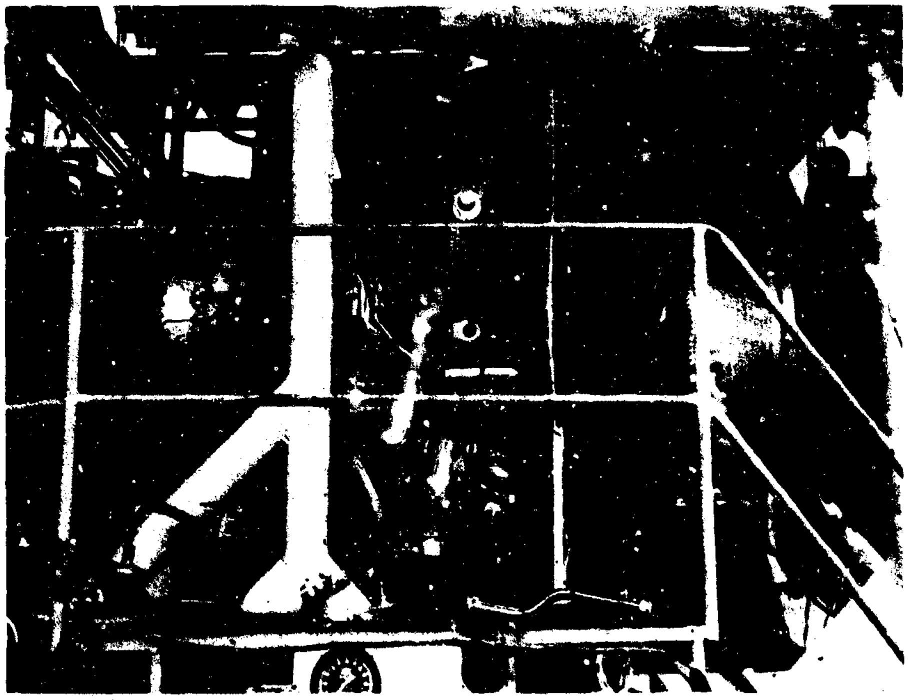


Figure 147. D-7 Complete System Fuel and Hydraulic Test Bench FE 5?137 EII

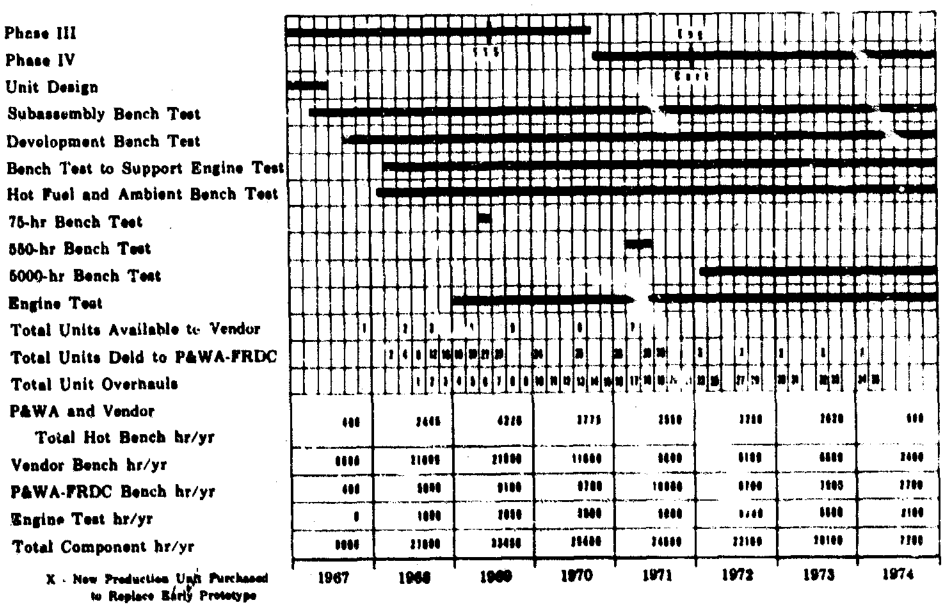


Figure 148. Unitized Fuel and Area Control Development Test Schedule FD 16527 EII

A total of 6250 hours of engine testing with the unitized control is scheduled to be completed during Phase III, including 100 hours of flight testing by the airframe manufacturer, and the simulated flight program at the Arnold Engineering Development Center at Tullahoma. An additional 19,500 engine test hours are planned in Phase IV. The ratio of bench test hours to eng-test hours scheduled, the ratio of the number of development controls to the number of development engines in the program, and the number of controls retained at the vendor for development testing at his facility are all based on history accumulated during the J58 and other engine development programs.

The component test program proposed for the unitized fuel and area control is discussed in detail in the following paragraphs. The program includes tests which are specifically applicable to only the unitized control as well as the more general tests which are applicable to all of the components of the engine control system.

The unitized control will be subjected to the following major performance and demonstration tests, either on an individual basis or as a component of the complete system:

1. 75-hour Hot Mission Cycle Component Bench Test.
2. Arnold Engineering Development Center Tests.
3. 75-hour Engine Flight Test Status Test.
4. 100 hours of Flight Testing.
5. 550-hour Component Bench Test which includes hot mission cycle and contaminated fuel testing.
6. 150-hour Engine Type Certification Test.
7. 5000-hour Component Bench Endurance Test.
8. 150-hour Component Bench Quality Assurance Tests.

The unitized control will also be subjected to the following tests which will be specifically tailored to the control.

Tests will be conducted to develop each subsystem within the control as individual assemblies as well as the complete control assembly. Control subsystem tests will be conducted prior to and continue after the initial control assembly to ensure the best control possible. These tests are described below:

Speed sensor and speed servo tests will be conducted to achieve the desired subsystem performance. Tests to be made include accuracy, load sensitivity, hot fuel compensation, frequency response, endurance, stability, contaminated fuel, and pressure sensitivity. It is anticipated that speed sensor and speed servo testing will consume approximately 1200 hours of test time and extend on an intermittent basis over 28 months of the Phase III program.

Other subsystems which will be subjected to tests similar to the speed sensor and speed servo include duct heater pressure ratio servo, duct heater exhaust nozzle control, engine inlet temperature servo, duct heater pump controller, servo pressure regulator, drain pressure regulator, power lever boost system, duct heater power lever scheduling servo, minimum pressure regulating valve, thermal bypass valve, and

duct heater cooling flow valve. Estimated test time for these subsystems is 8300 hours and will extend intermittently over 28 months of the Phase III program.

The gas generator and duct heater pressure regulating valves and sensors and throttle valves and servos will receive detailed study and early testing to develop the correct contour for the metering valves and for the pressure regulating valve. Tests will include runs to eliminate sensitivity to pressure levels and steady state pressure fluctuations, to achieve the desired frequency response, to ensure correct fuel temperature compensation, to establish the desired subsystem endurance, to accept contaminated fuel, to develop the desired accuracy, and to eliminate sensitivity to external loads. It is anticipated that pressure regulating valve and throttle valve development subsystem tests will require approximately 3300 hours and extend intermittently over 18 months from initial receipt of hardware.

All control filters will be tested as components to develop the optimum bypass valve opening pressure, contamination capturing capability, and pressure drop. The development objectives will be met by: testing filters of varying size such that the optimum length over diameter ratio giving an optimum filter area for minimum pressure drop will be determined; subjecting the selected configuration to contaminated fuel tests for determination of its ability to trap and hold contamination; and vibration testing to ensure mechanical integrity. Development testing of the filters is expected to require about 1000 hours and extend intermittently over seven months of the Phase III program.

Two-position valves will be tested to meet the requirements of low shutoff leakage, snap-action operation, operating with contaminated fuel, endurance and operation throughout the range of fuel pressure and fuel pressure fluctuations. It is anticipated that testing will require approximately 2300 hours and will extend intermittently over 15 months of Phase III.

The duct heater pressure ratio sensor will be subjected to extensive tests to ensure proper operation throughout the range of fuel temperature, duct total and static pressure, servo stroke, frequency response, and anticipated vibrations. The development time expected for the pressure ratio sensor is approximately 1000 hours and will extend over approximately 16 months of Phase III.

Other subsystems which will be subjected to test similar to the pressure ratio sensor are, the primary combustor pressure sensors, all control linkage systems, and the engine inlet temperature system. Specific emphasis will be placed on the bellows systems to ensure proper air temperature compensation and to develop a system which will not allow accumulation of any liquid or vapor condensation.

A complete JTF17 control system will be assembled and bench tested as soon as hardware becomes available. Many of the tests outlined and conducted on the subsystems will be repeated to ensure proper subsystem performance in relation to the overall control. Additional control tests will be conducted to develop the control into an efficient and accurate JTF17 engine control; these tests include such items as:

1. Performance tests to evaluate scheduling accuracy, repeatability, hysteresis, stability and transient response.
2. Performance tests to establish effects of fuel pressure fluctuation, fuel and ambient temperature variations, and fuel pressure level changes on sequencing mechanism operation.
3. System tests with other engine components such as the fuel pump and duct nozzle actuators to investigate possible interactions between components.
4. Performance tests to verify computer and analog programs.

These tests will accumulate approximately 21,000 hours of testing and will be conducted on a continuing basis throughout Phase III.

In addition to control development bench tests, tests will be conducted which are directly related to supporting engine development, this work being done on a continuing basis, starting with the delivery of the first unitized control to the Florida Research and Development Center.

New production control acceptance test procedures which were developed during the J58 program are planned for use in the JTF17 program. Each unitized fuel and area control will be subjected to bench tests with fuel at the maximum expected temperature. This has a two-fold purpose, to detect infant failures and to ensure proper temperature compensation against variations in output function accuracy. Each control will also be subjected to dynamic bench tests to prevent stability problems being encountered when the control is run with the remaining components of the control system on the engine.

Control engine tests will be conducted to determine specific operating schedules and desired response characteristics. Tests will include runs to evaluate acceleration and deceleration schedules by recording transient data, comparing the recorded data to the desired schedule, and revising the schedules to generate the optimum engine acceleration and deceleration performance. Other schedules to be similarly evaluated are compressor bleed, compressor inlet guide vanes, engine airflow, and duct heater initiation sequence. Steady-state tests will be conducted to evaluate the control scheduling accuracy and determine the proper steady-state schedules necessary to produce the desired engine performance. Such tests will include simulated aircraft mission cycles where the engine will be installed in an FRDC high Mach number high altitude chamber and aircraft missions very closely approximated. Data will be recorded at predetermined points along the simulated flight path. Steady-state data will include stability measures to ensure acceptable engine operation and long mechanical life. Tests will also be conducted with a simulated airframe fuel supply system to determine compatibility with the system.

Tests will be conducted on the alternative digital electronic airflow control module which will be capable of replacing the hydromechanical airflow control module on the unitized fuel and area control. The tests will be conducted on the electronic hardware as a separate module and also when integrated with the unitized control. The results will be compared to those obtained in a parallel program to be conducted on the hydromechanical hardware. The decision as to the type of unit to

be incorporated in production engines will be made in the prototype phase on the basis of experience with actual hardware during both ground and flight inlet-engine compatibility testing. Development bench testing of the electronic hardware is expected to require approximately 7100 hours during the Phase III program.

The test program for the unitized fuel and area control will be conducted on a more efficient basis than similar programs due to the rapid replacement concept incorporated in the control. Test bench utilization will be improved in that control changes will be accomplished in a greatly reduced time period. Thirty minutes will be required to change a unitized control on a bench, in comparison with three hours for a J58 main fuel control. Also the accessibility of the computer parts with removal of covers will decrease the time required to adjust or troubleshoot a unit.

Data analysis and evaluation for the control will consist of comparing the data recorded during each of the above tests to the design goals. In the case of subsystem testing, such as the speed servo, recorded data will be servo position versus speed input. A specific design curve will exist for the speed servo and the ultimate goal will be to develop the servo such that the design curve will be met regardless of external unscheduled inputs.

Assembled control data will consist of subsystem data and control output data. Specific design goals will exist in the form of fuel flow schedules for each power lever angle, engine inlet temperature, and burner pressure. When the design goal is not met, sufficient data will have been recorded to determine specifically which subsystem contributed to the scheduling error, thus permitting the error to be corrected. Other subsystems will produce actuation speeds, rates of actuation, and degree of compensation.

Evaluation of control system data obtained during engine tests will be essentially the same as the assembled control bench tests with the addition that engine performance data will also be evaluated. Control output functions will be adjusted as necessary to provide proper engine performance.

e. Unitized Control Test Schedule

The overall test schedule for the unitized fuel and area control is shown in figure 148.

3. Engine Pressure Ratio (EPR) Control

a. Introduction

(1) Background

The EPR Control is an airframe-mounted, solid state electronic digital computer. The EPR Control adjusts the Unitized Fuel and Area Control to maintain engine pressure ratio within close limits around a nominal schedule. The airframe-mounted EPR control will be offered

to the airlines as optional equipment. It is not required for satisfactory engine operation but will reduce the load upon the flight crew. A more detailed description of the EPR control design requirements, status, and the vendors proposing is provided in Volume III, Report B, Section III. Vendor selection will be made during the Phase II-C program.

This section of the proposal describes the techniques and facilities that will be used in the Phase III program to develop this control to the level of accuracy, reliability, and maintainability required for use with the JTF17 engine.

(2) State-of-the-Art

The proposed EPR control is within the immediate state-of-the-art in terms of the electronic components and the type of control. Report B, Section III of this proposal describes a similar device developed for the J58 engine.

b. Component Development Test Plant Objective

The bench and engine tests planned for the EPR control have one objective common to all, namely to experimentally determine and incorporate any design changes required to meet the accuracy, durability, and maintainability requirements for JTF17 operation.

The objectives of the specific EPR control tests are:

1. Engine Tests - Modified J58 Controls
   To confirm or experimentally optimize previously estimated EPR control gains, phase shifts, and other factors which influence control-engine stability.

2. Bench Tests - Electronic Subassemblies
   To demonstrate successful operation of the subassemblies in a simulated environment prior to EPR control assembly.

3. Bench Tests - Assembled EPR Controls
   To determine and incorporate, at the vendors plant, any required design changes prior to more extreme aircraft environmental tests.
   To confirm, at P&WA, vendor reported control performance.
   To calibrate EPR controls as required by the engine test program on electronic benches at P&WA.

4. Bench Tests - Aircraft Environmental
   To confirm that the EPR control will operate satisfactorily as a unit under simulated aircraft environmental conditions.

5. Bench Test - 550 Hour
   To confirm, on an electronic bench, that the EPR control has the capability of operating for an extended period under simulated flight conditions.

6. Bench Tests - EPR Control Mated with Unitized Fuel Control
   To confirm that an EPR control mated with a Unitized Fuel Control on a fuel bench will operate satisfactorily as a system.

7. Engine Tests
   To confirm that a Unitized Fuel Control mated with an EPR control will control the engine, within the required EPR schedule limits.

c. Description of Component Test Rigs and Facilities

(1) Component Test Rigs

The facilities currently available at FRDC for testing controls and the additional facility to be installed are described in the Introduction to the Test and Certification Plan. These facilities now include one electronic fuel control stand to perform input-output calibration of assembled EPR controls. Two additional electronic fuel control stands are scheduled to be operational at P&WA in December 1967, during the Phase III program.

(2) Component Test Facilities

An extensive standards laboratory and an environmental test laboratory are available to test EPR controls. These facilities are described in the Introduction to the Test and Certification Plan.

(3) Component Rig Instrumentation

Rigs for testing the EPR control will be supplied with precise indicating type instrumentation.

d. Component Test Programs

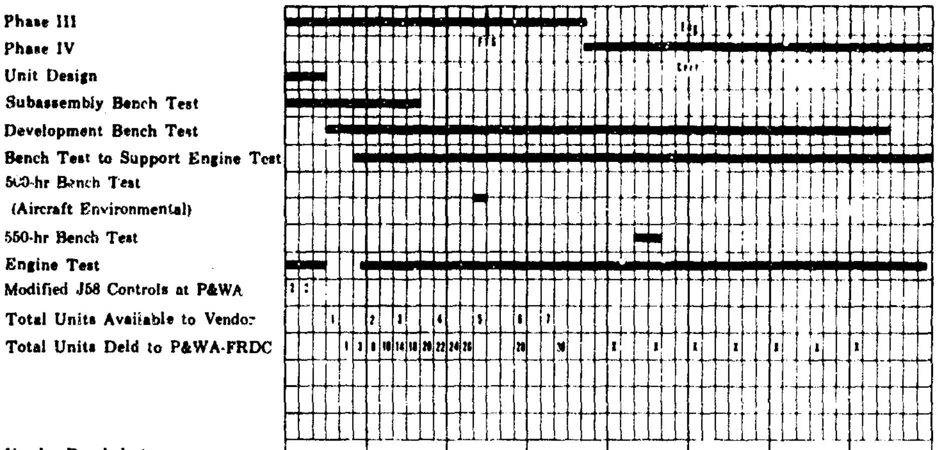
The component bench and engine tests planned for the EPR control are as follows. Figure 149 shows the proposed test schedule and test hours.

(1) Modified J58 Control Engine Test

Within two months after start of Phase III, four modified J58 controls will be subjected to electronic bench calibrations and incorporated into the initial engine test programs. EPR control factors affecting engine control stability will be experimentally optimized. Fifty hours of engine testing and twenty hours of bench testing at P&WA are scheduled for this program during the first six months of Phase III development.

(2) Bench Tests of EPR Controls

The EPR control lends itself to input-output electrical measurements on the bench. The inputs, electrical simulations of engine parameters, and the outputs will be measured with precise electrical instruments to determine the accuracy and repeatability of the control. During Phase III, 4585 hours of bench tests are planned at the vendors plant and 1085 hours at P&WA.



	1967	1968	1969	1970	1971	1972	1973	1974
Vendor Bench hr/yr	1000	1200	1500	1250	1500	1000	1000	450
P&WA-FRDC Bench hr/yr	250	250	300	400	400	400	400	200
Engine Test hr/yr	150	500	500	500	500	500	550	225
Total Component hr/yr	1450	2000	2300	2150	2400	1900	1900	875

Figure 149. EPR Control Development Test Schedule

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(a) Electronic Subassembly Tests

Subassemblies will be tested at the vendor's plant the first year of Phase III. The subassemblies will be given environmental tests, physical characteristic tests, and electrical-characteristic tests. The environmental tests will include temperature cycling, thermal shock, life (at elevated temperatures) and humidity. The physical characteristic tests will include vibration, shock, resistance to soldering heat, and terminal strength. The electrical characteristics tests will include tests of dielectric withstanding voltage, insulation resistance, and terminal resistance. The tests will be conducted in accordance with MIL-STD-202 Test Methods for Electronic and Electrical Component Parts. Six hundred hours of test time are planned for these tests.

(b) Assembled EPR Control Tests

Three experimental assembled EPR controls will be tested at the vendor's plant during the first year of Phase III. These units will be subjected to environmental and physical characteristics tests. Particular attention will be given to the effects of temperature, vibration, and shock loads on the accuracy of the EPR control. The first three assembled EPR controls received by P&WA will be subjected to environmental tests to confirm vendor-reported control performance. Six assembled EPR controls will be subjected to high temperature endurance testing at P&WA during Phase III. Push-to-check systems will be tested with assembled EPR controls to evaluate the convenience of operation, reliability, and accuracy of different methods of implementing this function. All controls will be calibrated and/or reprogramed at P&WA as required to support engine testing. Forty-two hundred hours are planned for these tests during Phase III.

(c) Aircraft Environment Test

During Phase III, one assembled EPR control will be tested at the vendor's plant over the full range of engine input variables and over the applicable aircraft environmental range. This test is planned for the same purpose as the 75-hour Component Bench Test. The environmental testing will be in accordance with applicable portions of MIL-STD-810, Environmental Test Methods for Aerospace and Ground Equipment, and MIL-E-5400, General Specification for Aircraft Electronic Equipment, plus particular P&WA requirements for this device. High and low temperature, low pressure, thermal shock, humidity, vibration, shock, acceleration, temperature-altitude cycling, explosive atmosphere, and radio frequency interference tests are included in this test program. Close coordination will be maintained with the airframe manufacturer and with the airlines in order to ensure compliance with their environmental requirements for airframe-mounted electronics. Five hundred hours of test time are planned for this program.

Design changes that result from these tests will be incorporated into these units for further vendor testing. P&WA will recommend and coordinate these changes.

(d) 550 Hours Test at Vendor's Plant

In Phase IV, one EPR Control will complete a 550-hour test. The test is planned for the same purpose as the 550-hour component bench test. This test will consist of accelerated aging by "soaking" at 200°F temperature in a nonoperating condition for 168 hours. The unit will then be calibrated at room temperature, disassembled and examined for deterioration due to aging.

The EPR control will then be subjected to 500 hours of Mission Cycle Endurance testing over a typical flight envelope of the JTF17 engine. After completion of the Mission Cycle Testing, the EPR control will be disassembled and inspected. A room temperature endurance test will be performed for a period of 50 hours. Any necessary experimentally determined design changes will be incorporated in the EPR control design.

(e) Testing of EPR Control Mated to Unitized Fuel Control at P&WA

The EPR controls will be electrically connected to a Unitized Fuel Control that will be mounted on a fuel control test bench. EPR control inputs will be varied and the performance of the control system will be monitored by Fuel Control Test Bench Instrumentation. This test will be performed on each EPR Control prior to engine testing. Three hundred and seventy hours of endurance testing of the mated units is planned during Phase III. This testing will be done prior to engine testing the EPR control.

(3) Engine Test Program

During Phase III, 1500 hours of engine testing is planned for the EPR control. The hours will be accumulated engine run time and will

be used to evaluate the EPR control accuracy, durability, and maintainability. The hours are shared with other components on the engine. Satisfactory operation of the control is evaluated on overall engine-control performance.

The engine FTS, AEDC tunnel tests, 100-hour flight test, 150-hour engine certification test, and the objectives of these tests as related to the control components are described in Section V of this report. The EPR control will be included as a control component operating in a simulated aircraft environment to demonstrate control performance and durability.

4. Gas Generator Fuel Pump

a. Introduction and State-of-the-Art

A more detailed description of the gas generator pump, the design requirements and status and the vendors proposing are provided in Vol. III, Report B, Section III. Vendor selection will be made during the Phase II-C program.

This gearbox driven pump receives fuel from the airframe fuel system, pressurizes it in two stages, and delivers it to the unitized fuel and area control. The centrifugal type boost impeller supplies pressurized fuel to the through-flow fuel filter which is part of the pump. Filtered fuel is directed to the high pressure gear stage and to the inlet of the hydraulic fuel pump. The pump gear stage supplies pressure at the level required to deliver metered fuel to the primary combustor.

Pump bench tests, complete system bench tests and engine tests are required to develop the gas generator fuel pump to the same degree of durability and reliability as current P&WA engine pumps in commercial operation. Testing will be initiated as soon as hardware becomes available, as illustrated by the development plan shown in figure 150.

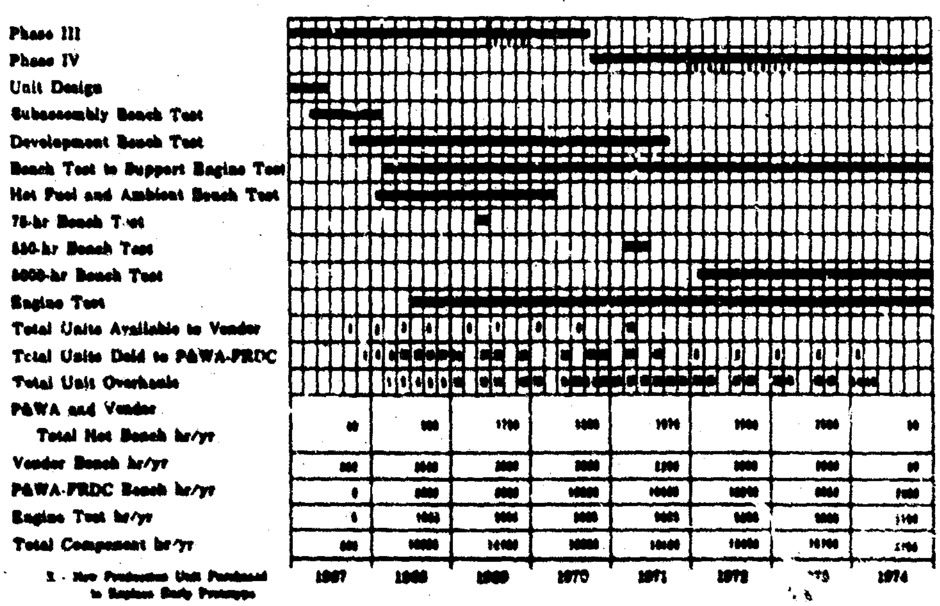

Figure 150. Gas Generator Fuel Pump Development Test Schedule FD 16617 EII

The gas generator fuel pump is of the same basic design and uses the same basic operating principles as the gear type fuel pumps used on current Pratt & Whitney Aircraft engines such as the JT3, JT3D, JT4, JT8, JT8D, and J58. The gearbox-driven, centrifugally-boosted, gear type fuel pump design was selected for the JTF17 engine because of the consistently reliable operation obtained with this type of pump on current engine models.

The test program for the gas generator fuel pump during Phase II-C has consisted of tests at the vendors to evaluate seal designs and material at elevated temperatures and investigate housing casting material properties. In addition, data obtained from the initial experimental engine test program using the similar J58 engine pump are being used to establish the required starting and maximum fuel flows and pressures. These data are being used as the basis for the fuel system design which establishes the fuel pump design.

b. Development Test Program Objectives

Subassembly bench tests will be conducted on items such as the boost impeller drive gear train, main pumping gears, full flow fuel filter, gear stage pressure relief valve, and the fuel oil cooler pressure drop control valve.

Development bench tests will be conducted on pumps to demonstrate the pump's ability to meet performance and durability goals, to detect the areas which require improvement and to substantiate improvement changes. A low inlet pressure test will be conducted to demonstrate the ability of the pump to operate satisfactorily with the aircraft boost system inoperative.

Bench tests in support of the engine development program will be performed to calibrate the pumps before and after engine tests, to demonstrate engine suitability and to investigate problems which are detected during engine operation.

These tests are conducted to develop and demonstrate efficiency, durability, performance characteristics, maintainability and safety of the pump.

c. Description of Component Facilities

The test facilities to be utilized in the development of the gas generator pump are described in detail in Volume V, Report B. The major portion of these facilities are available and have been used in the successful development of the J58 engine control system components. The benches are equipped with sufficient variable speed drives, horsepower, fuel capacity and instrumentation to test the fuel pump as a separate unit or a part of the fuel control system. One stand has the capability of simulating the complete engine fuel and hydraulic system driven by engine gearbox, mounted on engine cases, and utilizing the bill of material engine plumbing. Also, this stand has the capability of providing 300°F fuel temperature to the pump inlet and 1200°F inert ambient temperatures.

The following is a tabulation of some of the benches for testing the gas generator pump.

Test Stand Number	Program
D-11	Hot Fuel, Calibration and Room Temperature Ambient Endurance
D-12	Hot Fuel, Calibration and Room Temperature Ambient Endurance
D-18	Calibration and Dynamic Response Tests
D-7	Complete System Development and Heated Fuel and Ambient Endurance

d. Component Test Program

Component testing will be conducted at the vendor and P&WA facilities. The vendor testing will be directed by P&WA engineering and monitored by P&WA engineering as necessary. Special tests by the vendor will require a written report be submitted to P&WA for approval.

The Phase III program will require the use of 44 pump assemblies, of which 9 will be retained by the vendor. Twenty-three unit overhauls are scheduled during Phase III as shown on figure 150. A total of 30,775 hours of bench testing is planned during Phase III, and 40,175 hours planned through Phase IV. Included is 4110 hours and 7490 hours of testing at elevated temperatures during Phase III and Phase IV, respectively. Greater than 50% of the bench hours shown are accumulated supporting the unitized fuel control testing. The remaining test hours required to functionally check the pump, evaluate performance and stability, conduct endurance and environmental tests, and support the engine program, are based on history accumulated during the J58 and other engine programs.

(1) Subassembly Bench Test

1. Gear and bearing test will be conducted to determine efficiency and mechanical integrity.
2. Relief valve opening range, hysteresis, repeatability, and durability will be determined.
3. Boost Impeller and drive gear train test will be conducted to determine impeller performance gear train and bearing integrity.

(2) Assembled Unit Test

1. Pump overspeed testing to demonstrate the mechanical and pumping integrity under overspeed conditions will be conducted.
2. Thrust measurements will be taken on the boost impeller during pump operation to determine the thrust balance configuration which produces desirable bearing loads.

3. Vibration and structural test will be conducted to demonstrate the ability of the pump to function within the engine environment.
4. Burst test to determine the ultimate strength of the housing and seals will be conducted.
5. Low inlet pressure test will be conducted to determine the ability to operate with aircraft boost system inoperative.

e. Performance and Endurance Demonstration Tests

The component test program proposed for the gas generator fuel pump is discussed in detail in the preceding paragraphs, and shown in figure 6. The program includes tests that are specifically applicable to only the pump as well as the more general tests which are applicable to all of the components of the engine control system.

The pump will be subjected to the following major performance and demonstration tests, either on an individual basis or as a component of the complete system:

1. 75-hour Hot Mission Cycle Component Bench Test, except that the test will be supplemented by a 5-hour altitude proof test.
2. Arnold Engineering Development Center Tests.
3. 75-hour engine Flight Test Status Test.
4. 100 hours of Flight Testing.
5. 550-hour Component Bench Test which includes hot mission cycle and contaminated fuel testing.
6. 150-hour Engine Type Certification Test.
7. 5000-hour Component Bench Endurance Test.
8. 150-hour Component Bench Quality Assurance Tests.

5. Duct Heater Fuel Pump

a. Introduction and State-of-the-Art

The duct heater fuel pump supplies fuel through the unitized fuel and area control and the fuel injection system to the duct heater combustor where it is burned to produce augmentation thrust. The pump design uses an axial flow air turbine driven by engine compressor discharge air to drive the inducer-boosted centrifugal pumping element and uses fuel for bearing lubrication. The variable speed turbine is controlled to operate the pump at the minimum fuel pressure level required by the duct heater fuel metering and injection system. The primary advantage of this type of pump is that a minimum amount of heat is added to the fuel by the pump. This same type of augmentor fuel pump is being used successfully on the J58 engine.

A more detailed description of the duct heater fuel pump, the design requirements and status, and the vendors proposing are provided in Volume III, Report B, Section III. Vendor selection will be made during the Phase II-C program.

All Phase II-C JTF17 engine testing has been conducted using slightly modified J58 afterburner pumps to supply duct heater fuel flow. The fuel inlet inducers have been removed to allow a maximum flow rate in excess of the J58 maximum flow. The only other characteristic affected by removing

the inducer is that a higher inlet pressure is now required to prevent cavitation. Accordingly, the test stand fuel supply pressure is always maintained at a sufficient level to prevent cavitation.

Because the J58 and JTF17 pumps are very similar, including material type as well as mechanical configuration, related experience is being gained without finalizing the pump design until the completion of Phase II-C. This allows any changes resulting from this testing to be incorporated into the JTF17 duct heater fuel pump design at the lowest possible cost. For example, the Phase II-C engine test results will be used to optimize the predicted pressure-flow requirements. This revised data will be incorporated into the pump design to assure best efficiency.

b. Development Test Program Objectives

Subassembly bench tests will be conducted on items such as the inducer, inducer drive gear train, bearings, impeller, turbine and housings to demonstrate their durability, reliability, pumping characteristics, stress safety, maintainability, pressure balance, and suitability for use in the JTF17 duct heater fuel pump.

Development bench tests on the assembled pump will be conducted to demonstrate the ability to meet performance and durability goals, to detect the areas which require improvement and to substantiate improvement changes. Special bench testing will include tests to insure operation is unaffected by engine environments.

Bench tests in support of the engine development program will be performed to evaluate the pump before and after engine tests, to demonstrate engine suitability and to investigate problems which are detected during engine operation.

Engine test will include testing over the specified operating range and will provide compatibility evaluation with associated engine components.

c. Description of Component Facilities

The test facilities to be utilized in the development of the duct heater fuel pump are described in detail in Volume V, Report B. The major portion of these facilities are available and have been used in the successful development of the J58 engine control system components. The benches are equipped with sufficient variable speed drives, horsepower, fuel capacity and instrumentation to test the fuel pump as a separate unit or a part of the fuel control system. One stand has the capability of simulating the complete engine fuel and hydraulic system driven by engine gearbox, mounted on engine cases, and utilizing the bill of material engine plumbing. Also this stand has the capability of providing 300°F fuel temperature to the pump inlet and 1200°F inert ambient temperatures.

The following is a tabulation of some of the benches for testing the duct heater fuel pump.

Test Stand Number	Program
D-10, D-18, D-20	Room temperature fuel and ambient air development testing
D-11, D-12	Hot fuel and ambient air development testing
D-7	Complete system development and heated and ambient endurance

The benches are connected to the area centralized automatic data recording facilities as described in Volume V, Report B.

d. Component Test Program

Component testing will be conducted at P&WA and the vendor facility. The vendor testing will be directed by P&WA engineering and monitored as necessary. After the tests are completed, reports will be submitted by the vendor to P&WA.

The Phase III test program will require the use of 39 pump assemblies, 9 of which will be used by the vendor. The remaining 30 units will be used by P&WA for bench and engine testing. Twenty-three unit overhauls are scheduled during Phase III in addition to many pump teardowns to incorporate alternate or revised parts for evaluation.

The overall test program for the pump is presented in figure 151. As shown in this chart, 15,760 hours of bench testing will be accomplished during Phase III including 2050 hours at elevated temperature. During Phase IV, total bench test time will be 25,390 hours including 6435 hours at high temperature conditions. Engine time will be 6775 hours during Phase III, including 100 hours of flight testing, and 19,500 hours during Phase IV. Greater than 15% of the bench hours shown are accumulated supporting the unitized fuel control testing. The remaining test hours required to functionally check the pump, evaluate performance and stability, conduct endurance and environmental tests, and support the engine program, are based on history accumulated during the J58 and other engine programs.

e. Subassembly Bench Tests

1. Bearing tests to determine speed and load characteristics when subjected to the pump's environments
2. Turbine torque characteristics at various inlet air conditions
3. Turbine metal temperature gradient at maximum temperature conditions
4. Inducer fuel pumping characteristics at various inlet pressures, temperatures and fuel flow rates
5. Inducer gear train load and endurance tests
6. Turbine blade stress at maximum spins and temperatures

7. Inducer thrust load and thrust bearing requirements
8. Housing burst tests
9. Spin tests to destruction on turbine wheel and impeller.

f. Assembled Unit Bench Tests

1. Overall unit efficiency and operating characteristics
2. Response rate of pump pressure change to inlet air valve area change
3. Pumping characteristics at various inlet fuel pressures and temperatures
4. Vortex venturi overspeed protection operating characteristics
5. Endurance and reliability tests
6. Maintainability tests
7. Performance characteristics as affected by endurance time, temperatures and vibration
8. Turbine and pump impeller thrust balance evaluation on an operating pump.

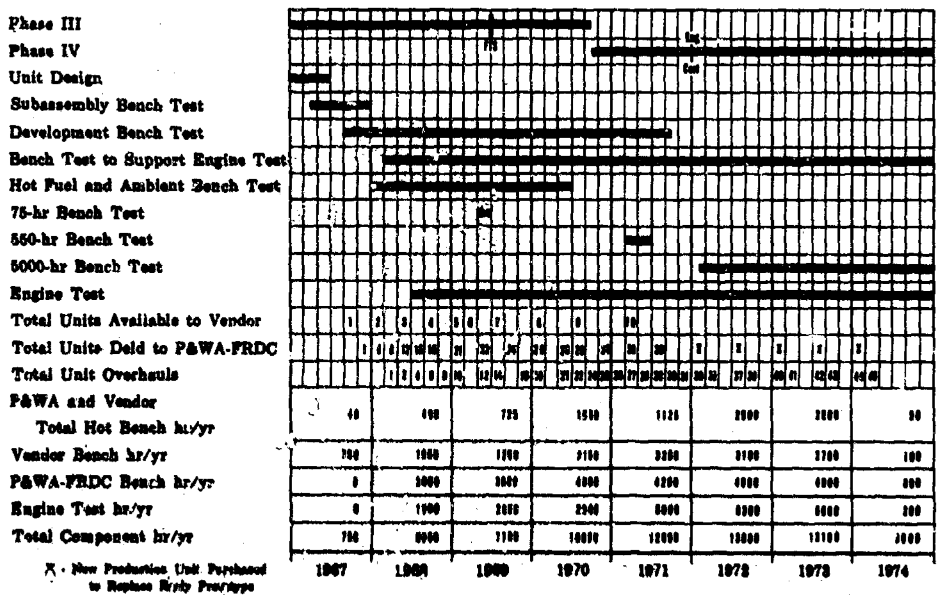

Figure 151. Duct Heater Fuel Pump Development Test Schedule

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g. Performance and Endurance Demonstration Tests

The component test program proposed for the duct heater fuel pump is discussed in the preceding paragraphs and shown in figure 151. The program includes tests that are specifically applicable to only the pump as well as the more general tests which are applicable to all of the components of the engine control system.

The pump will be subjected to the following major performance and demonstration tests, either on an individual basis or as a component of the complete system.

1. 75-hour hot mission cycle component bench test except that the test will be supplemented by a 5-hr altitude proof test
2. Arnold Engineering Development Center Tests
3. 75-hour engine Flight Test Status Test
4. 100 hours of flight testing
5. 550-hour component bench test which includes hot mission cycle and contaminated fuel testing
6. 150-hour Engine Type Certification Test
7. 5000-hour Component Bench Endurance Test
8. 150-hour Component Bench Quality Assurance Tests

6. Hydraulic Fuel Pump

a. Introduction and State-of-the Art

The hydraulic pump that is an engine gearbox-driven, variable flow, constant pressure piston type pump, provides engine fuel at high pressure to the fuel control and hydraulic system to position the augmentor duct exhaust nozzle and the reverser-suppressor. A more detailed description of the pump, the design requirements and status, and the vendors proposing are provided in Volume III, Report B, Section III. Vendor selection will be made during the Phase II-C program. The pump is supplied fuel from the gas generator pump boost stage and maintains a constant discharge pressure by means of a control servo. Pump bench tests, hydraulic system bench tests, and engine tests are planned to develop the pump to the reliability and durability levels required to meet JTF17 engine requirements.

Piston-type pumps have been utilized extensively for aircraft hydraulic systems using oil as the hydraulic fluid. Pratt & Whitney Aircraft, in cooperation with pump manufacturers, has developed piston pumps capable of meeting the severe requirements of the J58 and TF30 engines which use engine fuel as the hydraulic fluid, through development and use of wear-resistant materials. A similar piston-type hydraulic pump and fuel hydraulic system will be utilized for the JTF17 engine.

The J58 hydraulic pump is being utilized to meet the Phase II-C initial experimental engine hydraulic system requirements without modification or adjustment.

b. Development Test Program Objectives

Subassembly bench tests will be conducted on items such as pintle bearings, thrust bearings, socket bearings, servo valves, piston and cylinder sets and shaft seals to demonstrate their durability, reliability, response rates, safety, and suitability for use in the SST hydraulic system.

Development bench tests on the assembled pump will be conducted to demonstrate the ability to meet performance and durability goals, to detect the areas which require improvement and to substantiate improvement changes. Special bench testing will include tests to insure operation is unaffected by engine environments.

Bench test in support of the engine development program will be performed to evaluate the pump before and after engine tests, to demonstrate engine suitability and to investigate problems which are detected during engine operation.

Engine test will include testing over the specified operating range and will provide compatibility evaluation with associated engine components.

c. Description of Component Facilities

The test facilities to be utilized in the development and substantiation of the gas generator pump are described in detail in Volume V, Report B. The major portion of these facilities is available and has been used in the successful development of the J58 engine control system components. The benches are equipped with sufficient variable speed drives, horsepower, fuel capacity and instrumentation to test the fuel pump as a separate unit or a part of the fuel control system. One stand has the capability of simulating the complete engine fuel and hydraulic system driven by engine gearbox, mounted on engine cases, and utilizing the bill of material engine plumbing. Also, this stand has the capability of providing 300°F fuel temperature to the pump inlet and 1200°F inert ambient temperatures.

The following is a tabulation of some of the benches for testing the hydraulic fuel pump.

Test Stand Number	Program
D-11	Hot Fuel, Calibration and Room Temperature Ambient Endurance
D-12	Hot Fuel, Calibration and Room Temperature Ambient Endurance
D-18	Calibration and Dynamic Response Tests
D-7	Complete System Development and Heated Fuel and Ambient Endurance
D-16	Calibration and Room Temperature Ambient Endurance

The benches are connected to the area centralized automatic data recording facilities as described in Volume V, Report B.

d. Component Test Program

Component testing will be conducted at the vendor and P&WA facilities. The vendor testing will be directed by P&WA.

The Phase III program will require the use of 44 pump assemblies, of which 9 will be retained by the vendor. Twenty-three unit overhauls are scheduled as shown in figure 152. A total of 17,800 hours of bench testing is planned during Phase III, and 23,800 hours planned through Phase IV. Included is 2345 hours and 6245 hours of testing at elevated temperatures

during Phase III and Phase IV, respectively. Greater than 15% of the bench hours shown are accumulated supporting the unitized fuel control testing. The remaining test hours required to functionally check the pump, evaluate performance and stability, conduct endurance and environmental tests, and support the engine program, are based on history accumulated during the J58 and other engine programs.

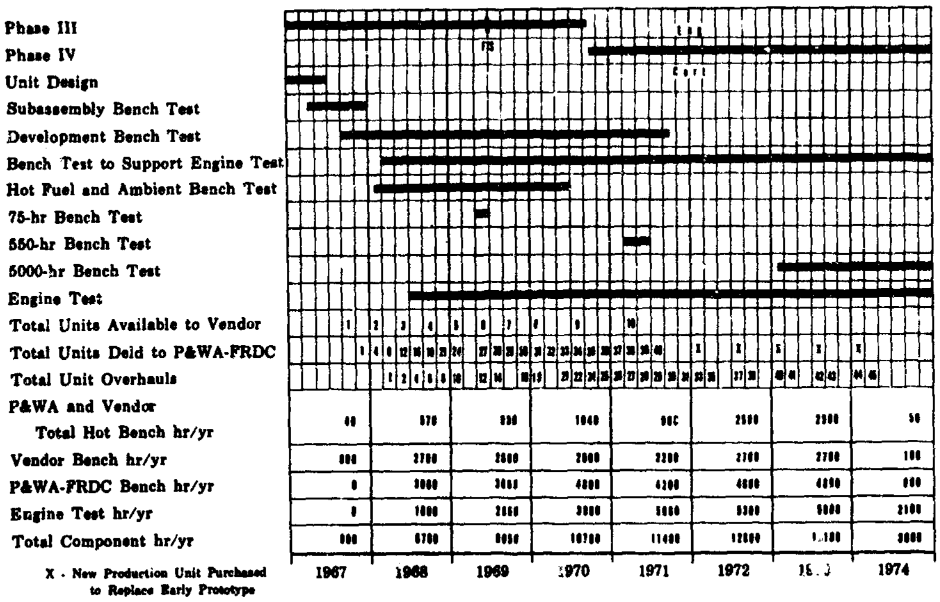

Figure 152. Fuel Hydraulic Pump Development Test Schedule

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e. Subassembly Bench Tests

1. Bearing tests to determine speed and load characteristics of each type when subjected to the pump environments.
2. Response rate and dead band characteristics for the servo valves to determine their suitability for using the hydraulic system and to determine their endurance and repeatability.
3. Endurance tests on the piston-cylinder assembly.
4. Rubbing endurance and pressure cyclic capability of the shaft seal.

f. Assembled Unit Bench Tests

1. Pump discharge pressure stability tests
2. Response rates of change in fuel flow vs pump pressure rise at various rpm's.
3. Endurance and reliability tests
4. Inlet pressure sensitivity tests
5. Temperature compensation characteristics
6. Capability of repeating the characteristics after the endurance and hot tests.

g. Performance and Endurance Demonstration Tests

The component test program proposed for the hydraulic fuel pump is discussed in the above paragraphs and shown in figure 152. The program includes tests which are specifically applicable to only the pump as well as the more general tests which are applicable to all of the components of the engine control system.

The pump will be subjected to the following major performance and demonstration tests, either on an individual basis or as a component of the complete system.

1. 75-hour Hot Mission Cycle Component Bench Test except that the test will be supplemented by a 5-hour altitude proof test.
2. Arnold Engineering Development Center Tests.
3. 75-hour engine Flight Test Status Test.
4. 100 hours of Flight Testing.
5. 550-hour Component Bench Test which includes hot mission cycle and contaminated fuel testing.
6. 150-hour Engine Type Certification Test.
7. 5000-hour Component Bench Endurance Test.
8. 150-hour Component Bench Quality Assurance Tests.

7. Ignition System

a. Introduction and State-of-the-Art

A more detailed description of ignition system, the design requirements and status, and the vendors proposing are provided in Volume III, Report B, Section III. Vendor selection will be made during the Phase II-C program.

The ignition system for the JTF17 engine provides ignition capability for both gas generator burner and duct heater over the entire range of the engine flight spectrum. The system is a 4-joule, low tension, capacitance discharge type, with an intermittent duty cycle. The system consists of two separate fuel cooled exciter packages, each containing two independent exciter circuits which supply electrical energy, through flexible leads, for one gas generator igniter and one duct heater igniter. The use of two fuel cooled exciter packages provide extended system life and reliability.

Bench evaluation and engine substantiation tests are required to develop the ignition system to the degree of reliability and durability which will contribute to an economical SST engine.

The selected low tension ignition system design is within current technology and offers the advantage of weight reduction, simplicity, cooler operation, and an igniter that is virtually unaffected by pressure at the tip or by electrode contaminations.

b. Development Test Program Objectives

Subassembly bench test will be conducted on capacitors, inductor, transformer, electron discharge tube, rectifiers, resistors, and the spark monitor circuit to develop and demonstrate efficiency, durability, and performance characteristics.

Development bench tests on the complete system will be conducted to demonstrate the ability to meet performance and durability goals, to detect the areas which require improvement and to substantiate improvement changes. Special bench testing will include altitude, explosion proof, vibration, impact, and sand and dust, fungus, sustained acceleration and humidity tests, to ensure that system operation is unaffected by engine environments.

Bench test in support of the engine development program will be performed to evaluate the ignition system before and after engine tests, to demonstrate engine suitability, and to investigate problems that are detected during engine operation.

Engine test will include starting tests over the specified operating range, and provide compatibility evaluation with associated engine components.

c. Description of Component Test Facilities

The component test facilities provide a capability for endurance testing at elevated temperatures, altitude testing, radio interference testing, and analyzing the system performance.

The endurance test rigs consist of ovens with inert ambient temperature capability of $-65^{\circ}F$ to $650^{\circ}F$ in which the entire ignition system may be placed and operated for extended periods of time. Each test rig is provided with an electrical power source capable of duplicating normal service inputs to the ignition system. The endurance rigs will be modified to meet the higher temperature requirements of the supersonic transport system. Each rig will also require a fuel supply system to provide cooling for the ignition exciters.

An altitude chamber capable of simulating sea level to 80,000 feet is used to determine "arc-over" in the ignition system at low ambient pressures and conduct "explosion-proof" tests. This test facility will require modification, to be completed by 1 July 1967, to accommodate the JTF17 requirements.

Radio interference testing will be conducted in a radio shielded room to demonstrate that the ignition system meets the specified requirements.

Test facilities re available to determine the performance of the ignition system in terms of energy release at both the exciter and the igniter. These performance tests will be conducted under the environmental conditions encountered by the supersonic transport.

The engine burner development rigs will be used in developing the engine ignition system. These rigs provide an ideal facility to test the ignition system under actual operating conditions over a wide range of the altitude flight envelope and to develop the optimum location and configuration of the igniters.

The following is a tabulation of some of the benches for testing the ignition system.

Test Stand Number	Program
G-3	Complete system development, heated fuel and ambient, and altitude endurance.
G-16	Variable voltage, altitude simulation bench.
G-17	Variable voltage, altitude simulation bench.
G-18	Variable voltage, endurance bench.

d. Component Test Program

Component testing will be conducted at the vendor and P&WA facilities. The vendor testing will be directed by P&WA engineering and monitored by P&WA engineering as necessary. Special tests by the vendor will require that a written report be submitted to P&WA for approval.

Each of the 35 experimental units planned for use at P&WA during the Phase III program will be subjected to performance tests such as the altitude chamber test, energy release tests, and radio interference tests prior to and on completion of endurance test, burner rig tests, or engine test. In this manner, each component is placed under constant surveillance; thus, the reliability and durability of the system is established and any problems which develop will be immediately observed and corrective action can be taken. Eight systems will be retained by the vendor for testing during the Phase III program.

Ten unit overhauls are scheduled during Phase III as shown in figure 153. The figure also shows that 27,925 hours of bench testing is planned during Phase III, and 13,075 hours planned through Phase IV. Included is 2875 hours and 5705 hours of testing at elevated temperatures during Phase III and Phase IV, respectively. These hours required to functionally check the ignition system, evaluate performance and reliability, conduct endurance and environmental test, support the engine program are based on history accumulated during the J58 and other engine programs.

Subassembly bench test and environmental tests will be conducted on the transformers, exciter housings, capacitors, resistor, rectifiers, spark monitor, electronic discharge tube, capacitors and leads.

Programs will be conducted in support of the engine development and to investigate problems. Vibration and structural tests will be conducted.

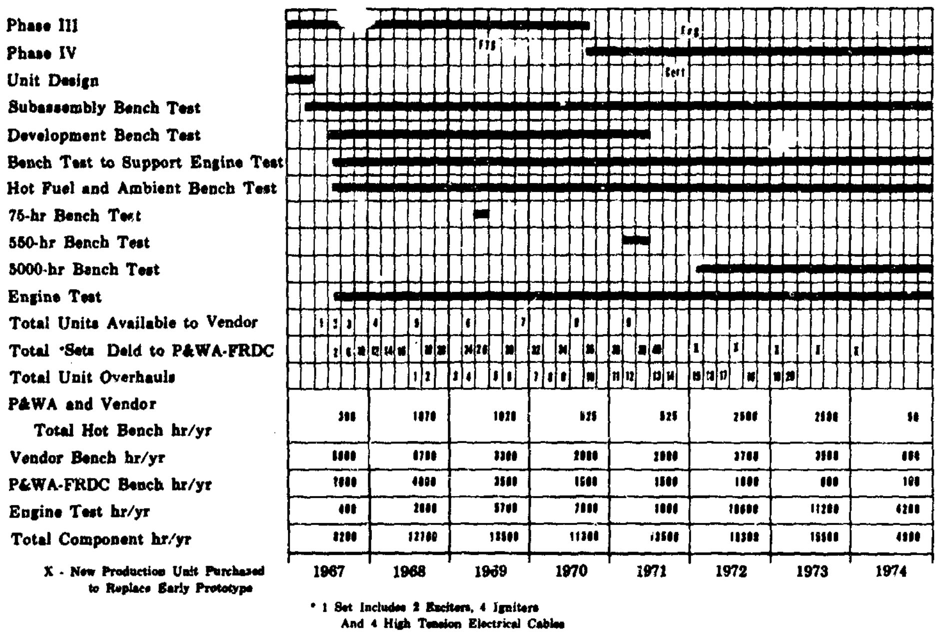

Figure 153. Ignition System Development Test Schedule

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The spark igniters will be subjected to performance and endurance tests at P&WA and the vendor facilities. The performance test will include energy released, breakdown voltage as a function of altitude and pulse frequency, and the effects of carbon and water fouling. Development tests will include electrode and semiconductor shunting material evaluation for increased durability, and the effect of the exciter voltage booster on igniter life.

Adequacy of the exciter cooling to maintain all detail components within their rated temperature will be determined by oven rig test and environmental engine tests on specially instrumental units.

Bench tests will be conducted to evaluate the durability and reliability of the exciter spark discharge monitoring circuit and the exciter voltage booster, which boosts the discharge voltage to 6000 volts as required by the igniter. Endurance tests will be conducted to establish duty cycle effect on complete system life.

The engine altitude relight envelope will be established during burner rig development testing of the primary combustor and duct heater.

Engine ignition tests will be conducted to evaluate sea level starting capability and to confirm the altitude relight envelope established by the combustor rig test within the facilities limits.

e. Performance and Endurance Demonstration Tests

The component test program proposed for the ignition system is discussed in detail in the preceding paragraphs and shown in figure 153. The program includes tests that are specifically applicable to only the

ignition system, as well as the more general tests that are applicable to all of the components of the engine control system.

The ignition system will be subjected to the following major performance and demonstration tests, either on an individual basis or as a component of the complete system.

1. 75-hour Hot Mission Cycle Component Bench Test
2. Arnold Engineering Development Center Tests
3. 75-hour engine Flight Test Status Test
4. 100 hours of Flight Testing
5. 550-hour Component Bench testing that includes hot mission cycle and contaminated fuel testing, except that the test will include variable voltage, vibration, radio interference, humidity, fungus, explosion proof, sand and dust, sustained acceleration, impact, and water fouling tests
6. 150-hour Engine Type Certification Test
7. 5000-hour Component Bench Endurance Test
8. 150-hour Component Bench Quality Assurance Tests.

8. Fuel Manifold Drain Valves

a. Introduction and State-of-the-Art

Fuel manifold overboard drain valves are installed in the gas generator fuel manifold and in both of the duct heater fuel manifolds of the JTF17 engine. These valves open to drain the fuel manifolds after the fuel system is shut off to prevent the possibility of fuel coking in the fuel nozzles. The three valves, which are all of a common P&WA design, are actuated by hydraulic signals from the unitized fuel and area control. A more detailed description of the fuel manifold drain valves, the design requirements, and the design status are provided in Volume III, Report B, Section III.

All Phase II-C JTF17 engine testing is being conducted using fuel manifold drain valves which were available from the J58 program. This same type of valve will be used on the prototype JTF17 engine with a minor housing redesign, required to increase the flow passages. The actuating piston, shaft seal and valve configuration has been retained to take advantage of the J58 experience.

b. Test and Certification Program Objectives

The test and certification program will develop the manifold drain valves to a high degree of reliability, durability, maintainability and safety for use on prototype and production engines.

c. Component Test Facilities

Nine test benches are available for testing the drain valves, including three benches capable of providing hot fuel up to 400°F and an inert ambient atmosphere up to 1200°F. Each test bench contains standard pressure gages, flowmeters and temperature indicators. In

addition, special instrumentation, recording equipment, function generators, and counters are available to each test bench when required. A more detailed description of the test facilities is included in Volume V, Report B.

d. Component Test Programs

The overall test program for the drain valves is presented in figure 154. As shown in the figure, 4710 hours of bench testing will be accomplished during Phase III, including 940 hours at elevated temperature. During Phase IV, total bench test time will be 18,790 hours, including 15,350 hours at high temperature conditions. Engine test time will be 20,925 hours during Phase III, including 300 hours of flight testing, and 58,500 hours during Phase IV. The drain valve assembly accumulates 3 hours of engine test time for each hour of engine operation because there are three drain valves on each engine.

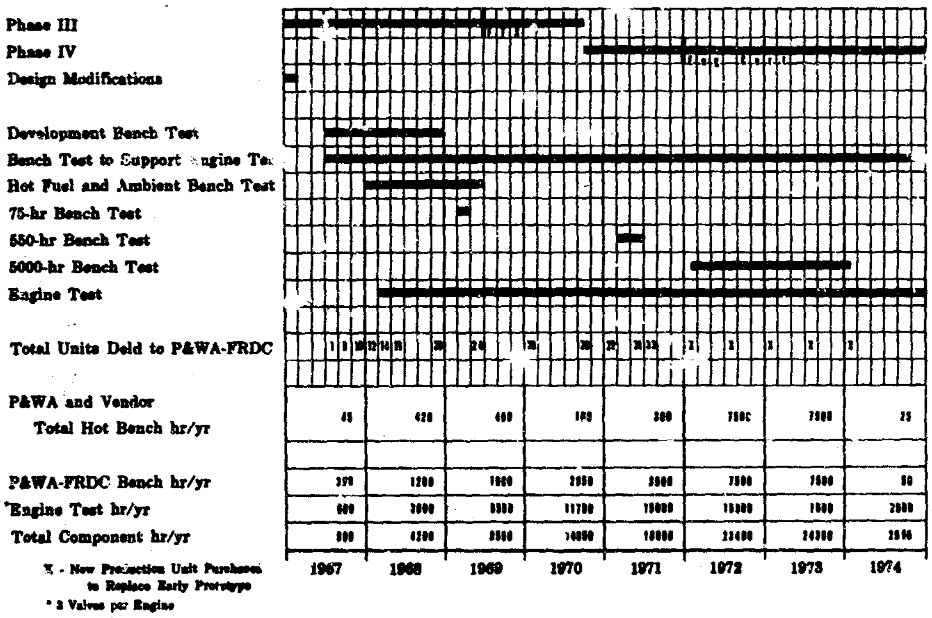


Figure 154. Fuel Manifold Drain Valve Development Test Schedule FD 16622 EII

The following tests will be accomplished during Phase III.

1. Acceptance tests per PWA CCS 126 will be performed upon each valve after initial assembly and after each subsequent build. This test includes functional and leakage checks. A copy of this test specification is available at FRDC for review.

2. Development test including housing burst test, leakage tests, actuating force tests, salt water compatibility tests, contamination tests and cycling tests will be conducted early in Phase III so that changes may be incorporated as necessary to establish a prototype valve Parts List within the initial 24 months. Approximately 1400 hours of bench testing will be accomplished, including 140 hours at elevated temperature.

e. Component Major Performance and Endurance Demonstration

The component test program proposed for the fuel manifold drain valves is discussed in detail in the preceding paragraphs and shown in figure 10. The program includes tests that are specifically applicable to only the valves, as well as the more general tests that are applicable to all of the components of the engine control system.

The valves will be subjected to the following major performance and demonstration tests, either on an individual basis or as a component of the complete system as applicable:

1. 75-hour Hot Mission Cycle Component Bench Test
2. Arnold Engineering Development Center tests
3. 75-hour engine Flight Test Status Test
4. 100 hours of Flight testing
5. 550-hour Component bench test which includes hot mission cycle and contaminated fuel testing
6. 150-hour Engine Type Certification Test
7. 5000-hour Component Bench Endurance Test
8. 150-hour Component Bench Quality Assurance Tests.

9. Compressor Bleed Valves

a. Background

The JTF17 compressor air bleed valves are poppet-type valves, very similar to the poppet bleed valves that have demonstrated high reliability in the commercial JT8D and military JT8 engines. These valves have accumulated in excess of 500,000 hours commercial operation and 200,000 hours military operation. Design refinements resulting from the extensive service experience obtained from these engines have been incorporated into the JTF17 valve design. Eight of these valves are used on the JTF17 engine. These valves are mounted on the gas generator case, inside of the duct heater, and must operate before and after long periods of exposure to high temperatures; therefore, they must give reliable, trouble-free operation in excess of the scheduled engine life. These valves will be closely monitored during engine and compressor rig tests to determine that valve performance meets the engine requirements.

The air bleed valve is an air-actuated, spring-loaded poppet valve as shown in figure 155, that bleeds high compressor 5th-stage air to the cavity surrounding the gas generator to relieve starting loads. Pressure to open the valve is supplied to the actuator piston from the compressor discharge as scheduled by the unitized fuel and area control. The coil spring mechanism is located external to the high compressor gas stream and will assist the valve to open toward the gas stream and will hold the valve open during engine shutdown. At a given high compressor rotor speed, the open air signal pressure will be vented to ambient, and the differential pressure between fan discharge and ambient will close the valve. This positive differential pressure holds the valve in the closed position during engine operation. The poppet valve will be exposed to a maximum gas temperature of 1000°F, while the valve operating mechanism, which is external to the high compressor in the gas generator cavity, will be subjected to a 700°F maximum temperature. Bleed valves of this

type incorporated in the Phase II-C JTF17 engines have been operated satisfactorily during engine and hot environmental component tests. The JTF17 valve detail description, mode of operation, and design status are presented in Volume III, Report B, Section III.

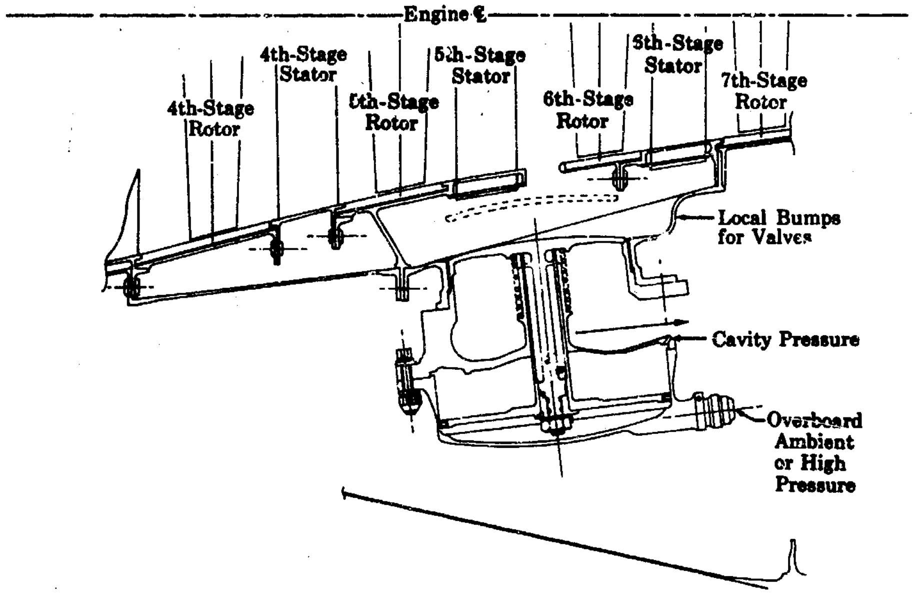


Figure 155. Compressor Air Bleed Valve Installation — FD 17016 EII

During Phase II-C, cycle tests were conducted on two compressor bleed valves. The test program consisted of a calibration in accordance with the Component Calibration Schedule, cycling of the valve for 5000 operating cycles in a 1050°F environment, post-test calibration, disassembly, and inspection. The pre- and post-test calibration data were in good agreement, and the detail parts of each valve were in excellent condition. Assuming a 2.5-hour mission time and assuming that the valve cycles (open to close to open) twice per mission, 5000 cycles of the valve is equivalent to 2500 missions and 6250 flight hours.

The FTS and Certification Tests of the valve will consist of a calibration before and after the engine FTS and Certification Test. The assembly and disassembly of the valves will be witnessed by PWA Quality Control and Government representatives. Pre- and post-test measurements will be recorded to determine the amount of wear and distress on the parts and to determine that all parts performed satisfactorily. Calibration data will be thoroughly analyzed to determine whether any deterioration of the unit has occurred.

The bleed valve test program objectives, facilities and equipment, the test program, acceptance criteria, and the usage schedule are described in the following sections.

b. Test Program Objectives

The bleed valve test program objective is to produce a reliable and durable valve capable of meeting or exceeding the design specifications through engine tests, compressor rig tests, and valve rig tests. Because of the operating environment, the valves are designed to work with dry lubricants and have negligible valve seat and piston ring leakage.

The data will be analyzed to determine conformance within the specifications. If the pre- and post-test data comparison indicates deteriorated performance, the valves will be disassembled, inspected, and redesigns initiated by the condition of the detail parts. These inspection results will be recorded to accumulate a statistical history of defects, such as individual part wear, valve seat leakage, piston ring leakage, and spring deterioration to establish a part failure frequency from which reliability can be estimated, based upon a single-failure concept. These data will also provide the basis to establish service limits for use during line maintenance and overhaul.

The installation of the valve on the engine and overhaul of the valves will be closely monitored to develop the overall performance and maintainability of the units.

FTS and Certification of the valves will be accomplished in conjunction with the engine FTS and Certification Tests.

c. Facilities and Equipment

The test facilities and equipment required for this testing are available from the Phase II-C program with minor modifications. These static benches are equipped to provide air flows similar to engine operation, ambient to 1000°F environmental temperatures, the necessary control valves and cyclic control units, and standard instrumentation for measuring and recording airflow, air pressures, and temperatures. Cycling of the valve through its full stroke is monitored by photoelectric cells that trigger a cycle counter. A dry-ice-type cold chamber will be provided by fabricating an ice chest around a calibration test chamber. DM 49A static bench is a calibration stand and D 17A test stand provides environmental test capability (figure 156).

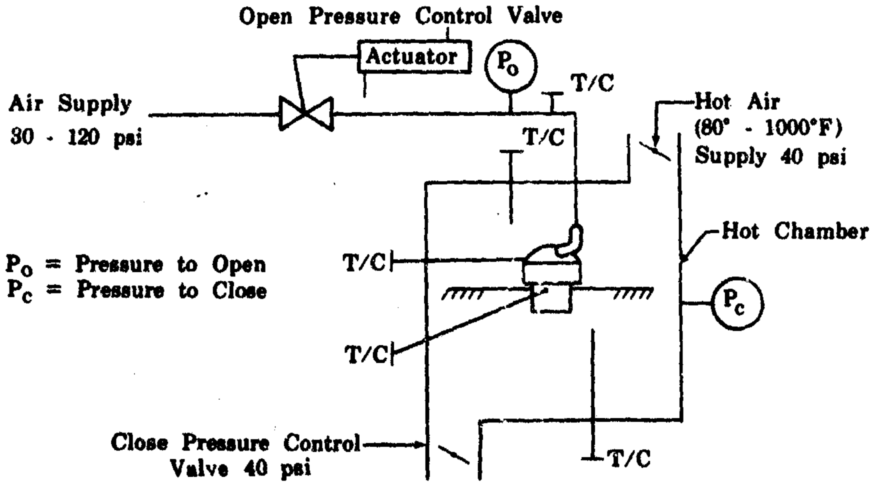


Figure 156. Compressor Bleed Valve Test Schematic FD 16613 EII

d. Test Program

In addition to close monitoring of the valve performance during engine tests and compressor rig tests, the development of the valves will be accomplished through test programs consisting of calibration, cycle and response, contamination and flow capacity as described in the following paragraphs.

(1) Calibration

The bench test calibration is performed to determine the valves conformance to the Component Calibration Schedule, which defines pressure to actuate, actuator piston ring leakage and poppet valve seat leakage limits.

(2) Cycle and Response

A high temperature cycle test will consist of a precycle soak at a temperature of 1000°F for one hour followed by 5000 operating cycles over a period of 28 hours at this temperature.

A cold temperature cycle test will consist of a precycle soak at a temperature of -65°F for 4 hours, followed by 2500 cycles over a period of 14 hours at this temperature.

In each test, the response of the valve will be determined.

(3) Contamination

Satisfactory cyclic operation of the valve with contaminated air shall mean contaminated air will not in itself precipitate a sudden failure, but may cause gradual deterioration of performance or abnormal wear of the parts. Foreign matter in the air to the extent of 1.46×10^{-4} pound/pound air, to consist of not less than 68 percent SiO_2, shall have a particle-size analysis as follows:

Particle Size, Microns	Percent of Total by Weight
0-5	39 ± 2
5-10	18 ± 3
10-20	16 ± 3
20-40	18 ± 3
Over 40	9 ± 3
Through 200 mesh screen	100

The valve will be cycled at room temperature 500 cycles at 4-minute intervals over a period of 34 hours. Contaminated air will be continuously flowing through the valve at the rate of one pound per second.

(4) Flow Capacity

The flow characteristics of the bleed valve will be determined to ensure that the valves meet the design specification relative to pressure drop versus air flow.

e. Acceptance Criteria

Acceptance of the bleed valves to meet the design requirements is based upon valve performance within the Component Calibration Schedule limits as recorded prior to engine operation and that after engine operation to the mission cycle for the specified time, the wear or distress of the parts is insufficient to preclude further satisfactory operation after normal overhaul.

f. Usage Schedule

The number of units and the test hours required through Phase III are shown below:

1. Total number of units - 214

2. Type of Test — Total Hours

	Type of Test	Total Hours
a.	Calibration	1200
b.	Contamination	300
c.	Cycle and Response	600
d.	Flow Capacity	100
e.	Total Bench Time (sum of a, b, c, d)	2200
f.	Component Rigs	2100
g.	Engine	8000

The data are shown in bar-graph form in figure 157.

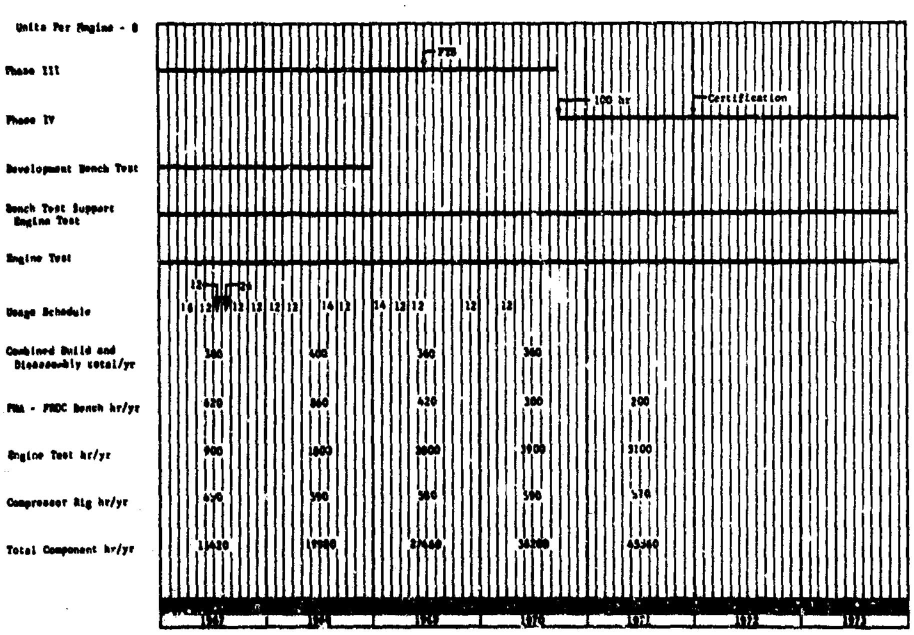


Figure 157. Proposed Development Plan - Compressor Bleed Valves

FD 16614
EII

10. Actuators, Hydraulic and Pneumatic

a. Introduction

(1) Background

The JTF17 engine incorporates linear actuators that operate the high compressor variable inlet guide vanes (IGV), the variable area duct nozzle, and the reverser/suppressor clamshells. These actuators are required to perform through a wide range of working fluid pressures and temperatures and ambient temperatures, to maintain stable operation under varying load conditions, and operate with essentially zero overboard leakage.

The inlet guide vane actuator is a tandem hydraulic-pneumatic unit as shown in figure 158. The hydraulic section is controlled by hydraulic signals from the unitized fuel control to operate the inlet guide vanes from the SLTO to cruise (start) position by pushing against the air piston, which is attached to the vane linkage mechanism. The air cylinder section actuates the inlet guide vanes into and out of the aerodynamic brake position when selected by the aircraft pilot. During normal operation, air pressure acting upon the rod side of the air piston causes the inlet guide vanes to follow the movements of the hydraulic piston or to reset the aerodynamic brake for normal operation. During emergency shutdown of the engine, the air pressure acts upon the head of the piston to move the inlet guide vanes into the aerodynamic brake position. The supply air for normal and emergency operation is taken from the airframe cabin air bleed environmental control system to provide an energy source that is external of the engine. The air cylinder section is similar to the design of the actuator section of the compressor bleed valve. The compressor bleed valve description and its Phase II-C test results are noted in the compressor bleed valve test section.

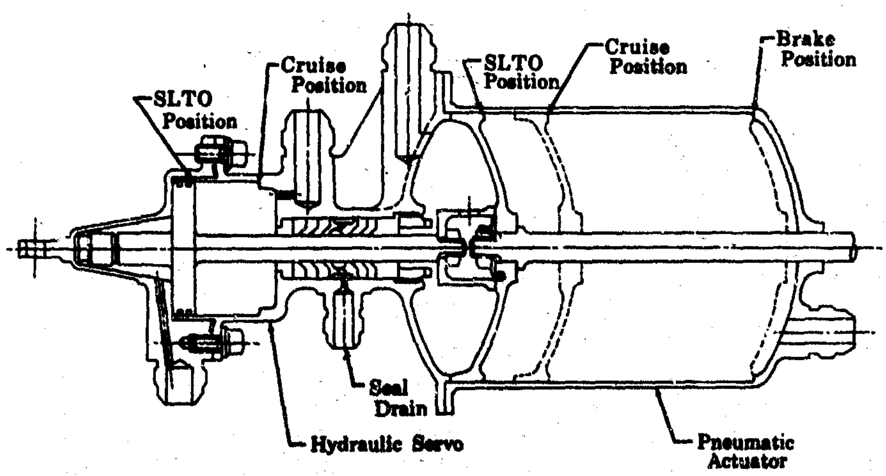


Figure 158. Hydraulic-Pneumatic Actuator for JTF17 Inlet Guide Vane System — FD 16394 EII

The hydraulic duct nozzle actuators are fully modulating units, as shown in figure 159 which position the variable duct nozzle area as scheduled by the unitized fuel control.

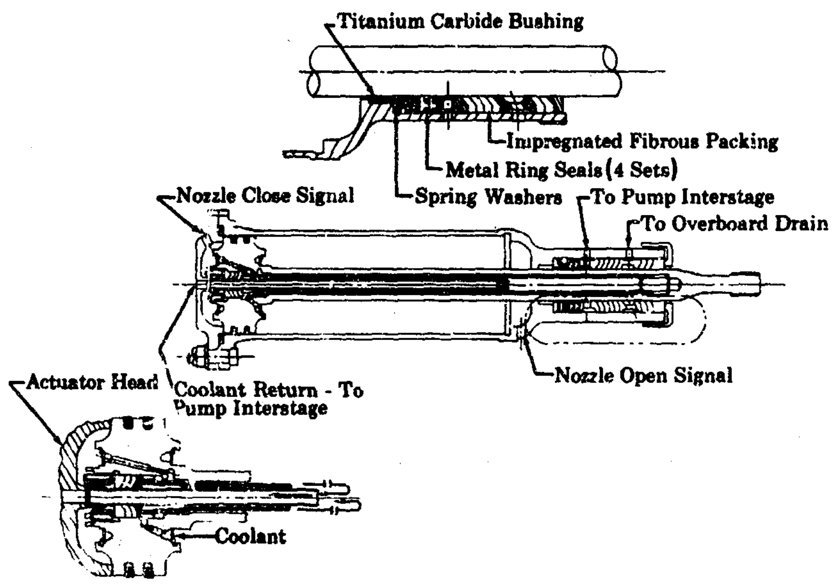


Figure 159. Duct Heater Nozzle Actuator FD 16395 EII

The reverser-suppressor actuators are hydraulic units, as shown in figure 160, which position the reverser doors (clamshells) into the SLTO or reverse positions as scheduled by the unitized fuel control; these clamshells are aerodynamically actuated between SLTO and cruise positions.

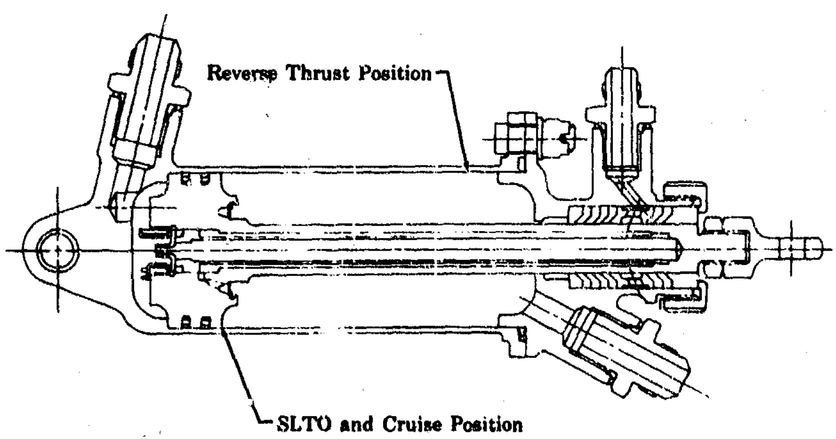


Figure 160. Reverser-Suppressor Clamshell Actuator FD 17028 EII

Two inlet guide vane, four duct nozzle and two reverser-suppressor actuators are utilized per engine. Detail descriptions, modes of operation, and design status are presented in Volume II, Report B, Section III.

These linear hydraulic actuators for the JTF17 engine are based on concepts which have already demonstrated high reliability on the high performance J58 and TF30 engines by successful completion of several 150 hour engine certification tests and during extensive flight test. These proven design concepts are: (1) use of engine fuel as the working fluid, (2) internal cooling of the piston rod, internal rod seals, rod seal cavity and actuator housing, (3) low pressure dynamic seals, (4) high temperature metal and organic seals for contamination tolerance in the dynamic location and reusable metal seals in the static locations, (5) hardfacing of wear surfaces, (6) filters in the actuator ports, and (7) a mounting system that reduces piston rod bearing loads induced by misalignment. These concepts are the result of extensive actuator development by PWA for the J58 engine program, which involved over 32,000 hours bench test time, including 1000-hour endurance tests on two 2-position actuators that were subjected to the following conditions:

1. Ambient temperature - 800°F
2. Fuel inlet temperature - 400°F
3. Actuator stroke - 2.010 in. (full)
4. Actuator cycle rate - 2 cycles per hour
5. Open-close pressure - 2500 psi
6. Overboard drain leakage:
   a. Pretest calibration - 0 cc/min
   b. Post-test calibration - 0.4 cc/min (1st actuator)
      0 cc/min (2nd actuator)
   c. Average during test - 0.2 cc/min
   d. Acceptance limit - 1 cc/min

The piston, piston rings, and the actuator rod surface with tungsten carbide coating were in good condition after disassembly, although carbon, dust, and other types of foreign material were found on the exposed actuator shaft. A slight shrinkage and hardening of the organic dynamic rod seals was noted. The exposed unprotected external surfaces of the actuator were severely corroded. These surfaces are now coated with a nickel-aluminum plasma spray (PWA 53-21) to prevent corrosion of the Greek Ascoloy material (AMS 5616).

The JTF17 hydraulic actuators are designed to take full advantage of J58 engine experience, which revealed that dynamic seal leakage resulting from the location of the actuator in a very hot environment is the most likely actuator problem. The JTF17 engine actuator environments at the cruise Mach number and altitude are 290°F or more lower in temperature than those of the J58 engine. Employing the proved concepts from J58 engines in the design of the JTF17 actuators will produce reliable hydraulic actuators that have a negligible amount of dynamic seal leakage. Metal and organic dynamic seals that are capable of thousands of hours of endurance are being investigated. Test programs to develop long time dynamic seal endurance will constitute a major portion of the planned Phase III effort.

Similar hydraulic duct nozzle actuators designed for the Phase II-C JTF17 engine have operated successfully during engine and hot environment component tests. A 75-hour hot environment component design verification test was conducted as follows:

1. Ambient temperature - 900°F
2. Fuel inlet temperature - 350°F for 4 hours, 150°F for 1 hour - cycle repeated every 5 hours
3. Actuator stroke - 1 in. (nominal full stroke - 4.2 in.)
4. Actuator cycle rate - 90 cycles per minute
5. Open-close pressure - 1500 to 2000 psi
6. Overboard drain leakage - 2.5 cc/min average during endurance (normal acceptance limit - 5 cc/min).

Pre- and post-test calibration data were in excellent agreement, and the actuator parts showed little or no distress. The above conditions represent a typical actuator endurance test leading to FTS and engine Certification.

The actuator FTS and Certification tests will include a calibration prior to and after the engine FTS and Certification test. Pre- and post-test measurements will be recorded to determine the amount of wear and distress on the parts and to determine that all parts performed satisfactorily. Calibration data of pressure to actuate, external leakage, stroke, and cooling flow rate will be thoroughly analyzed to determine deterioration of the unit.

The actuator development objectives, facilities and equipment, test programs, evaluation criteria, usage schedule and alternate system plans are described in the following sections.

b. Test Program Objectives

The primary goal of all testing is to expose any design and performance deficiencies of the actuators and to evaluate corrective action. The major areas of actuator development will be directed toward dynamic seal development for durability and toward evaluation of the use of titanium alloy in lieu of Greek Ascoloy material (AMS 5616). This program is intended to provide a substantial weight savings. Extensive testing, which will include hot and cold environmental tests, calibration, heat transfer, endurance, and contamination rig tests and engine tests, will be accomplished. The test program for each type of rig is shown in table 17. This program contains the design specifications that each actuator shall meet or exceed to ensure that the actuator performance during engine tests will meet the complete engine control system stability, reliability, and endurance requirements. A cold environmental test will be conducted in conjunction with the cold environmental test of the control system. The test program parameters and conditions for each type of test will consist of the appropriate items listed below:

1. Pressure to actuate, psi
2. External leakage limits, cc/min
3. Stroke measurement, in.
4. Skin temperature, °F
5. Seal cavity temperature, °F
6. Cooling flow rate, pph
7. Fuel temperature, °F
8. Environmental temperature, °F
9. Piston rod cycle rate, cycle/min.

Table 17. Proposed Development Test Plan

Type of Test	Test Conditions: Fluid Temp °F	Environ. Temp °F	Cooling Flow Rate, pph Fuel	Length of Stroke, Inches	Cycle Rate, Cycle/min.	Test Items or Parameters: Pressure to Actuate	External Leakage	Stroke Meas	Skin Temp	Seal Cavity Temp	Cooling Flow
CALIBRATION	AMB.	AMB.	150-350	PER BLUE-PRINT	12	X	X	X			X
CONTAMINATION	AMB. to 350	AMB. to 700	150-350	*	*		X		X	X	X
GENERAL DEVELOPMENT											
A. Hot Environment	350	700	150-350	*	*		X		X	X	
B. Heat Transfer	AMB. to 350	AMB. to 700	0-500	N/A	N/A				X	X	X
C. Endurance	AMB. to 350	AMB. to 700	150-350	*	*		X				X
D. Cold Environment	Temp to Obtain 12 centi-strokes	Temp to Obtain 12 centi-strokes	150-350	*	*		X		X	X	X
ENGINE	AMB. to 350	AMB. to 700	150-350				X		X	X	X

* To be representative of engine operation

The data will be thoroughly analyzed to determine conformance with the specifications. If the pre-and post-test data comparison indicates deteriorated performance, the actuator will be disassembled, inspected, and redesigns initiated as indicated by the condition of the detail parts. These inspection results will be recorded to accumulate statistical history of defects, such as individual part wear, housing and piston scoring, filter contamination, dynamic seal leakage, and contamination and erosion, to establish a part failure frequency from which reliability can be estimated, based upon a single failure concept.

The accessibility of the actuators on the engine, and the ease of overhaul of the actuator will be closely monitored to determine the overall acceptance of the units.

FTS and Certification tests of the actuators will be accomplished in conjunction with the engine FTS and Certification Test.

c. Facilities and Equipment

The test facilities and equipment required for the above testing are available from the J58 actuator development program. These static benches are equipped to provide engine fuel at flow schedules similar to engine operation, fuel temperatures from ambient to 350°F, environmental temperatures from ambient to 700°F, and standard instrumentation, control valves, etc., required to conduct each test. DM 46 and DM 47 static benches are calibration stands, and D5 and D6 test stands provide environmental test capability (figure 161). For a detailed description, refer to Volume V, Report B.

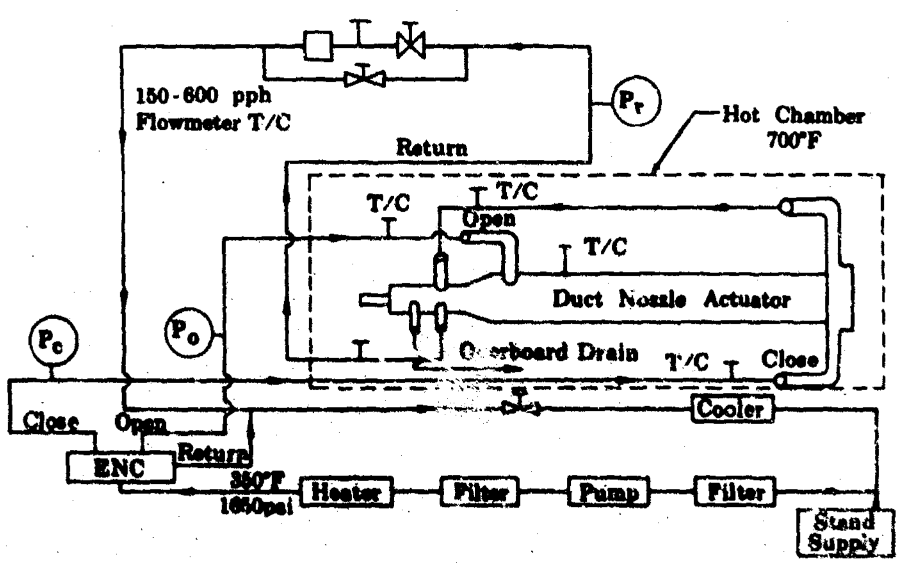


Figure 161. Duct Heater Nozzle Actuator Test Schematic FD 16512 EII

d. Test Programs

To develop titanium alloy actuators that have the reliability of the current actuators and to substantially improve dynamic seal durability, the following development programs will be utilized:

(1) Calibration

The bench calibration test is performed to the Component Calibration Schedule requirements, and includes pressure to actuate, external leakage, stroke and cooling flow rate.

(2) Contamination

Satisfactory cyclic operation of the actuators with contaminated fuel shall mean that contaminated fuel will not in itself precipitate a sudden failure, but may cause gradual deterioration of performance or abnormal wear of the parts. Foreign matter in the fuel to the extent of 8 grams per 1000 gallons, to consist of not less than 68% SiO_2, shall have a particle-size analysis as follows:

Particle Size, Microns	Percent of Total
0-5	39 $\pm$ 2 by weight
5-10	18 $\pm$ 3 by weight
10-20	16 $\pm$ 3 by weight
20-40	18 $\pm$ 3 by weight
Over 40	9 $\pm$ 3 by weight
Through 200 mesh screen	100 by weight

The test will be conducted as follows. After 70 hours of endurance cycling, at least 8 grams per 1000 gallons of contaminant as specified above shall be added to the supply tank. The fluid and contaminant shall be agitated continuously to maintain a homogeneous mixture and the functional cycling continued for 70 hours. During this testing the fuel filters shall be cleaned or replaced and the complete system, including the fuel tank shall be flushed at 20-hour intervals. At the completion of the 70 hours, all the full flow filters shall be removed from the system. An additional 10 hours of testing shall then be performed with at least 8 grams per 1000 gallons of the contaminant specified above with no filtration.

Control of ambient or fluid temperatures shall not be required during this test.

(3) General Development

(a) Endurance and Hot Environment

These tests consist of cycling the actuator at a rate that simulates engine operation. The actuator stroke is reduced to a value that represents the most frequent step changes in duct nozzle position.

(b) Heat Transfer

The cooling flow rate required to prevent coking of the fuel, provide adequate life, and contribute immeasurably to the heat rejection of the engine are determined in these tests.

(c) Cold Environment

Independent cold environment tests are not planned for each actuator. This test for the actuators will be integrated with the overall control system cold environment test.

(e) Acceptance Criteria

Acceptance of the actuators to meet the design requirements is based upon actuator performance within the Component Calibration Schedule limits as recorded prior to engine test and that after engine operation according to the mission cycle for the specified time, the wear or distress of the parts is insufficient to preclude further satisfactory operation after normal overhaul.

f. Usage Schedule

The actuator usage through Phase III will be as follows:

Type of Test	Total Hours	Test Hours for Each Actuator		
		IGV	Duct Nozzle	Reverser/Suppressor
Calibration	1000	300	600	100
Contamination	1500	500	500	500
Gen. Development	33900	7600	19200	7100
Total Bench Time (sum of 1, 2 & 3)	36400	8400	20300	7700
Engine	8000	16000	32000	1200
Component Rigs	2100	4300	N/A	7000

The total number of each type of actuator required through Phase III is indicated below:

Type of Actuator	IGV	Duct Nozzle	Reverser/Suppressor
Total Quantity	63	99	30

These data are presented in bar graph form in figure 162.

g. Alternative Program

A completely mechanical actuation system for the inlet guide vanes, duct nozzle, and reverser-suppressor systems will be studied during the early part of Phase III to evaluate the feasibility of simplifying the actuation system and to assess the advantages and disadvantages of mechanical system development in relation to the JTF17 hydraulic actuation system. The evaluation will be based upon the anticipated effort that will be required to develop the mechanical actuation system for reliability and durability, the degree that the state-of-the-art must be extended to meet the objectives, and the weight of the system as compared to the hydraulic actuation system.

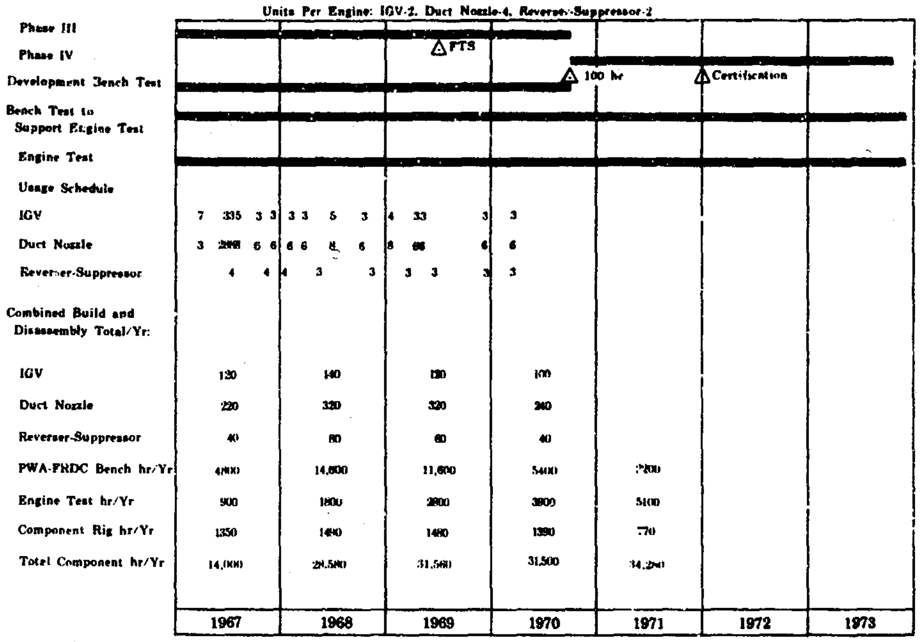


Figure 162. Proposed Development Plan - Hydraulic Actuators

FD 16616
EII

D. FUEL AND LUBRICATION SYSTEMS

1. Lubrication System

a. Introduction

(1) Background

Lubrication systems designed by Pratt & Whitney Aircraft presently in operation in commercial jet engines such as JT3, JT4, and JT3D engines can operate in the engine for thousands of hours before overhaul. The JT3D engine has achieved an 8,000 hour time before overhaul (TBO) using these systems. The GG3G-1 industrial gas turbine engine using the basic JT4 lubrication system, recently completed 16,000 hours of operation without overhaul at a utilization rate of over 95% of available time. Engine operation at altitudes greater than 80,000 feet attests to the capability of Pratt & Whitney Aircraft lubrication system concepts.

The complete JTF17 engine lubrication system is composed of the following subsystems:

1. Lubricant supply system
2. Scavenging system
3. Breather system

The lubricant supply system serves the dual purpose of lubricating rubbing contact areas and removing heat from contacting and surrounding wall areas. It includes the oil tank, pressure pumps, filters, pressure regulator valve and plumbing. The system is described in detail in Volume III, Report B, Section IV. All engine lubricating oil is gravity-fed from the oil tank to a positive displacement main oil gear pump in the engine accessory gearbox. From the pump discharge, the oil is routed to the main oil filter system prior to being cooled in two fuel-oil coolers in series. The oil pressure and flow rate downstream of the coolers are maintained constant regardless of change in engine speeds or pressure drops across the filters and coolers by a pressure regulator located in the engine accessory gearbox. From the pressure regulator sense line junction at the fuel-oil cooler exit, the engine oil is distributed through tubing to locations that require cooling and lubrication. All bearings, seals, and gears receive the oil through jet nozzles at appropriate locations in the bearing compartments and gearboxes. Additional protection for the bearings is provided by passing the oil through filtering screens upstream of the oil jets.

Oil that has been supplied to the bearings and gears drains into sumps where it is picked up by scavenge pumps and returned to the oil tank. Five pumps are used in the JTF17 engine scavenge system. Three of these are located in the accessory gearbox and handle return flow from the No. 1 and 2 bearing compartment sump, the No. 3 compartment, and the accessory gearbox. The other two are located in the main gearbox and the No. 4 bearing compartment. The inlet of each pump is covered with a large-area, coarse mesh strainer to prevent metal particles and other foreign objects from damaging the pumps. These pumps are gear-driven and use gears for positive oil displacement. All of the scavenge pumps deliver oil to the oil tank through a de-aerator located in the oil tank.

Eight oil monitoring units are provided in the scavenge system for isolation and detection of impending problems within the oil system. These monitoring units are magnetic chip detectors and are located in the main oil filter, oil tank, gearboxes, and scavenge lines. The locations of the units were selected so that they could be inspected and maintained easily during ground maintenance checks. These chip detectors can be designed with an option so that any conductive matter, ferrous or nonferrous, will close a circuit and actuate a warning light in the cockpit. The self-closing feature of the chip detectors permits visual checks and removal of deposited particles while the engine is running.

The breather system vents the air that flows past bearing compartments seals to the atmosphere. The primary functions of the system are to maintain the lubrication system pressure at a level that prevents oil loss and to provide an adequate inlet pressure for the oil pumps. The system incorporates provisions for removing entrained oil from the breather air. Interconnecting tubing maintains breather pressure at an equal level between compartments, oil tank, and gearboxes. The remainder of the breather system is composed of a de-oiler and a breather pressurizing valve. The de-oiler is a gear-driven, rotating vane and plate assembly located in the accessory gearbox just upstream of the

breather pressurizing valve. The breather pressurizing valve maintains a pressure in the system equal to the altitude ambient pressure from sea level to 35,000 feet. This is accomplished through the use of an evacuated bellows in the valve housing. At 35,000 feet an ambient pressure of 4 psia is reached, at which point the valve is normally closed. Above this altitude the actuation of the bellows maintains a minimum of 4 psia. As a safety feature, a relief poppet-type valve is incorporated in the main valve housing to prevent overpressurizing the breather system in the event of a bellows failure or a compartment seal failure.

The Phase III lubrication system test plan is described in paragraphs c and d, following. Paragraph c describes the development test program of individual component units in the lubrication system. Paragraph d describes the test plan to develop the lubricant subsystem in bearing compartment rigs, an oil system and gearbox integrated test rig, and engine testing.

(2) Present Phase II-C Component Status

The objective of the Phase II-C program relative to the lubrication system was to demonstrate the compatibility of Type II oils with the system components. These objectives have been achieved in that lubricants from two suppliers conforming to the PWA 521 Type II oil specification have demonstrated the ability to adequately cool and lubricate the bearings, seals, and gears in the experimental JTF17 engine and component test rigs. To accomplish these objectives, over 73 hours of engine testing and over 250 hours of bearing and seal rig testing were completed through July 1966. The rig testing included modified J58 seal rig tests, bearing rig tests, and bearing compartment rig tests at simulated JTF17 engine compartment and engine operating conditions throughout a typical engine mission cycle. Complete laboratory tests were conducted to evaluate the candidate lubricants. These tests included viscosity changes with engine and rig testing, evaporation loss and foaming tendency characteristics at varying temperatures, corrosion-oxidation stability on engine metals, and deposition and degradation characteristics in an engine oil system simulator. The results of these tests have been reported in the Phase II-C monthly progress reports to the FAA and are summarized in Report B, Section IV-F. The same rigs used in Phase II-C will be used in Phase III; also, a new oil system and gearbox rig will be used for endurance testing up to 1000 hours to further evaluate the Type II lubricants for the JTF17 engine.

b. Lubrication System Test Objectives

A primary objective of the Phase III lubrication system test program is to investigate the compatibility of the Type II lubricants conforming to the PWA 521 Type II specification with the lubrication system components and the engine bearing compartments and gearboxes over the entire predicted range of engine and airframe operating conditions. Tests at environmental conditions simulating those anticipated in flight will serve to search out and correct problems resulting from the flight environment before they are encountered in actual flight.

Engine and rig testing of the lubrication system will be required to develop and verify the adequacy of the components to satisfy the airframe and JTF17 requirements for engine reliability, maintainability, overhaulability, and meeting FTS requirements.

c. Component Test Program

The planned lubricant test programs are discussed in paragraph d. The information obtained from these tests will be used to determine which lubricants conform to the PWA 521 Type II oil specification and should be evaluated in component test rigs and the JTF17 engine. Correlation of the lubricant test data and the lubrication system test data will aid in the overall development program of the prototype JTF17 engine.

Early testing of lubrication system components is planned to ensure that the JTF17 engine meets performance and reliability goals within the engine program milestone schedules. These tests will either confirm the adequacy of the component design or lead to new designs that will ensure that engine goals are met. Calibration testing of adequate designs will be completed at least nine months before FTS, as shown in figure 163.

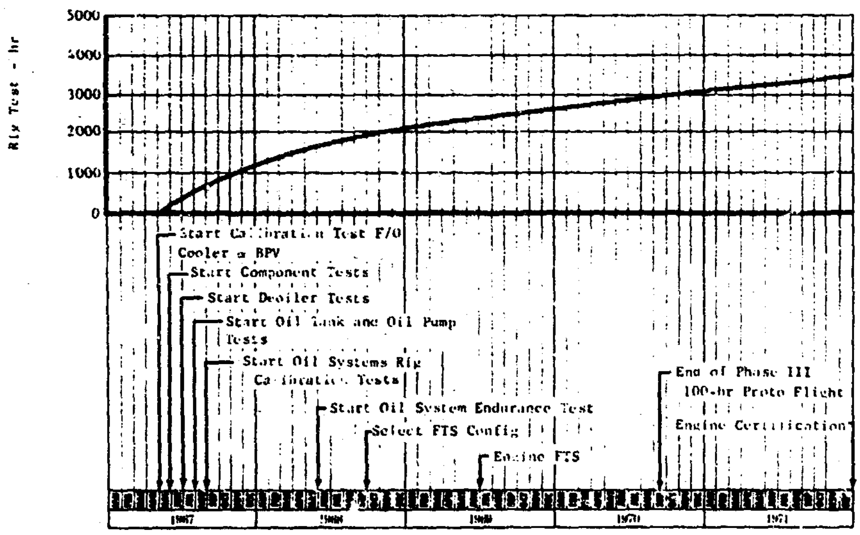


Figure 163. Lubrication System Component Test Program — FD 16624 EII

Lubrication system component testing will accumulate a minimum of 3000 hours of calibration and endurance rig testing during Phase III. During the Phase IV component improvement program, 1000 hours of lubrication system component rig testing is planned.

(1) Description of Lubrication System Component Rigs

Standard rigs have been in operation for many years to evaluate pumps, de-oilers, and other components. Only minor adaptations will be required for these rigs to evaluate JTF17 lubrication system components. Engine parts will be used in these rigs.

A typical lubrication component test rig installation is shown in figure 164, which shows a pump rig mounted on a test stand with associated stand equipment. This stand is capable of simulating all JTF17 engine lubricant system operating conditions. Actual rig testing will be extended beyond the expected range of engine-imposed conditions.

Figure 164. Typical Oil Pump Test Rig Installation

FE 59907
EII

(2) Test Description

The following rig testing will be conducted on the JTF17 lubrication system components:

(a) Oil Tank and De-Aerator

The oil tank is a welded steel container that is shaped to fit the engine contour at the fan discharge case. The total tank capacity is 6.22 gallons. The oil tank also has provisions to determine the oil level, fill and drain the tank, detect the presence of metallic particles, and de-aerate the scavenged oil. For a complete description of the oil tank, see Volume III, Report B, Section IV.

To test the strength and functionability of the engine oil tank, overpressure and vacuum testing beyond the JTF17 requirements will be made. The tank will also be subjected to vibratory stress levels beyond the JTF17 requirements. In addition to this testing and the experimental engine testing of the oil tank, the functionability of the de-aerator will be determined by circulating aerated oil at simulated engine operating temperatures and pressures through the oil tank and measuring the level of foam in the tank through the use of tank-mounted motion picture cameras.

Modifications, such as additional integral internal antidistortion rods that tie the two halves of the tank together, additional internal plumbing brackets, and changes to the shape and size of the de-aerator, will be made until oil foam in the tank is reduced to a minimum and all tank-engine-airframe compatibility and pressure requirements have been met.

(b) Fuel Oil Cooler

The JTF17 engine incorporates two single-pass, baffled, shell- and tube-type heat exchangers in series, using fuel to cool the oil. The first cooler in the series circuit uses duct heater fuel flow as the coolant and the second uses gas generator fuel flow. Both oil coolers have bypass valves that shunt the oil around the cooler if the pressure drop exceeds 28 psi. The duct heater oil cooler also has a thermostatically operated bypass valve that diverts the duct heater fuel around the cooler when necessary to preclude exceeding the specified fuel temperature limit at the heater fuel nozzles. Additional information on the design and function of the engine fuel-oil coolers is provided in Volume III, Report B, Section IV.

Presently available oil cooler rig stands (flow benches) will be used to determine the functionability of the oil coolers and of the pressure and thermal bypass valves. These flow benches calibrate the coolers to determine the heat transfer ability of the cooler and the pressure drop of the oil and fuel passing through the coolers. The bypass valves will be cycle-tested to determine the repeatability of the valves during endurance tests at varying temperatures and pressures duplicating those experienced during mission cycling of the engine. During engine testing, the amount of coke buildup in the coolers will be determined by oil pressure drop instrumentation. Post-engine-test heat transfer and oil pressure drop tests will be conducted to establish oil coking services limits of the coolers. Thermostatic valve calibration will be made by measuring oil and fuel temperatures during engine testing. Oil temperature cycling endurance tests will evaluate the ability of the valves to repeat the oil bypass setting. Burst and corrosion testing will be conducted at pressures up to 1450 psig, which far exceeds the JTF17 engine requirement.

(c) De-Oiler

The engine de-oiler is a gear driven, rotating vane and plate assembly located in the top of the accessory gearbox just upstream of the breather pressurizing valve. The breather air flows inward radially and oil droplets are centrifuged radially outward. This valve is described in detail in Volume III, Report B, Section II-G.

The test rig that will be used in the development of the JTF17 de-oiler is a standard Pratt & Whitney Aircraft de-oiler rig with an a-c electric drive motor and a housing simulating a typical engine gearbox. The de-oiler testing will evaluate the adequacy of the JTF17 engine de-oiler design and alternate designs to handle 200 scfm of oil-saturated breather air with a minimum oil loss and pressure drop. The oil loss at 200 scfm, the expected engine breather flow with one shaft seal failure, should not exceed 3 lb/hr. To accomplish this testing, a known quantity of oil is mixed with a known airflow and passed through the de-oiler. The de-oiler pressure drop is recorded throughout a one hour test and the quantity of oil remaining after the test is recorded. This test will be repeated at simulated breather airflows up to 600 scfm. A plot of oil loss vs breather flow is then evaluated to determine the adequacy of the de-oiler design. Modification, such as vane straightening or changing the size of the de-oiler, will be made if required.

The de-oiler will also be endurance tested in engines and gearbox rigs to prove its durability.

(d) Breather Pressurizing Valve

Existing test stand rigs will be modified for the JTF17 breather pressurizing valve development. For a complete description of the valve and its funtion, see Volume III, Report B, Section IV-E. Tests will be run in these stands to determine the valve opening and closing points, the pressure drop across the valve at airflows simulating those expected in the event of engine seal failures and at engine operating breather flows and pressures, and the functionability of the poppet safety valve in the assembly. These tests consist primarily of pressurizing the inlet of the valve or evacuating the ambient vent discharge line, and measuring the pressure drop across the valve and the air flow through the valve. Approximately ten valves will be subjected to cycling endurance tests during the Phase III program.

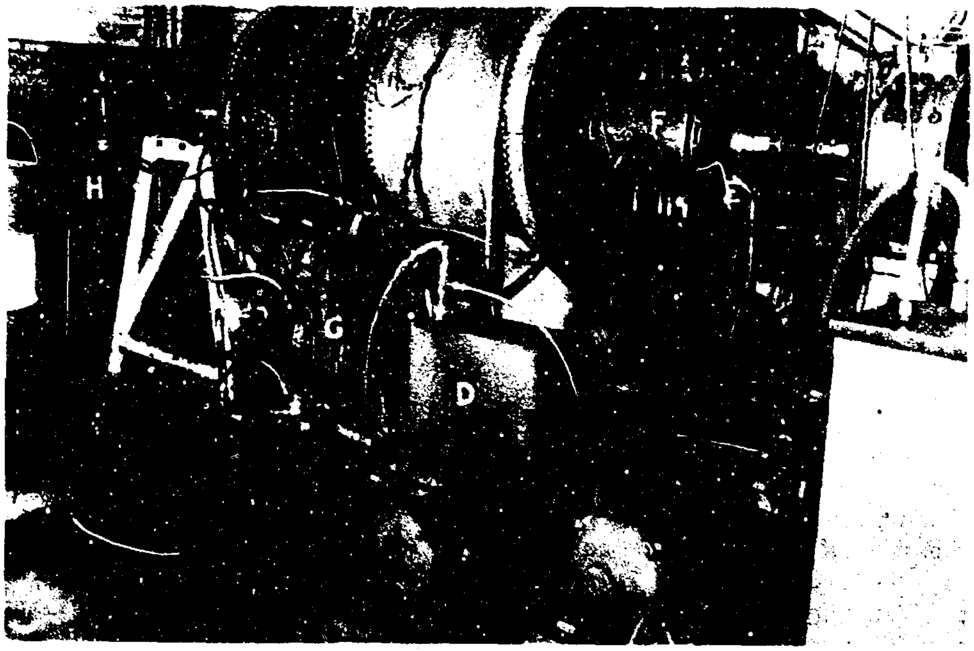
(e) Main Oil Pressure and Scavenge Gear Pumps

These P&WA-designed pumps will initially be calibrated by determining the flow rate and pressure rise across the pumps at varying speeds. These calibration tests will ensure that the pumps are capable of supplying the oil flow rates required to meet JTF17 engine needs at all engine operating conditions. Three of each type of pump will be endurance tested for 300 hours each at simulated engine mission cycle pump speeds and oil temperatures to determine the pump bearing journal and gear wear rate. The pumps will be modified and retested if required to meet flow or endurance requirements. Alternative journal bearing materials will be evaluated in endurance tests.

d. Lubrication System Test Program

Lubrication system rig tests have been included in every Pratt & Whitney Aircraft engine development program. The rigs consist of either large sections of the engine in rig form or of an entire "bladeless" engine with associated gearboxes, which is driven by an external-drive motor. The JTF17 lubrication system component test program will include rigs of both types. Figure 165 is a photograph of a JT4 engine lubrication test rig similar to the rig to be used in the JTF17 program.

Both types of rigs will be used to evaluate the effects that long-time operation and resultant dirt ingestion and sludge build-up have on cooling effectiveness, oil distribution, and bearing and seal operation. They will also be used to evaluate the effectiveness of changes to the system in correcting any problem areas encountered.



RIG 9478E MOUNTED IN X-4 STAND

A-DRIVE GEARBOX
B-GEARBOX OIL TANK
C-GEARBOX OIL PUMP
D-HYDROLIC LOADING SYSTEM PUMP AND TANK
E-HYDROLIC PRESS. INTO LOADING PISTON
F-THRUST BEARING RIG USED TO GIVE AXIAL THRUST TO ENGINE SHAFT
G-STAND OIL HEATER
H-RIG OIL TANK

Figure 165. Rig 9478E Mounted in X-4 Stand

X-11672
EII

(1) Description of Rigs

(a) Engine Oil and Gearbox System Rig

This rig will consist almost entirely of engine parts that will in essence be a complete JTF17 engine except that fan, compressor, and turbine blading will be removed to reduce windage losses. The only non-standard parts required will be adapters necessary to mount the "bladeless" engine and to provide the necessary external drive. Exact in-flight environmental conditions will be created in the total lubrication and breather system. To provide the necessary airflow, air heating, breather system and external drive facilities, a test stand similar to the one shown in figure 165 will be required.

(b) Engine Bearing Compartment Seal Rig

Three full-scale engine compartment seal test rigs will be used in the development of the lubrication system. These rigs consist of the

entire engine compartments including the engine bearings, seals, bearing housings, heatshielding, and shafts. These rigs are being used successfully in the current JTF17 Phase II-C program to develop the engine bearings, seals, and lubrication system. The success of these rigs and similar rigs used in the J58 engine program has demonstrated the value of their continued use in the development of the JTF17 engine lubrication system.

(2) Test Description

Over 7000 hours of calibration and endurance tests in the engine oil system and gearbox rig, and an additional 6800 hours of testing in the three bearing compartment seal rigs will be conducted during Phase III to develop the JTF17 lubrication system. After FTS, any lubrication difficulties encountered during experimental and flight test operation will be evaluated, redesigned, and retested on the oil system and gearbox rig. Since the lubrication system tests will be run in the oil system and gearbox rig and in the bearing compartment seal rigs, in conjunction with the development of these engine components, the rate of testing and rig builds to develop the lubrication system are shown in paragraph B7 (Seals, Bearings, Gearboxes). These tests will be run at varying speeds, pressures, and temperatures to simulate engine operating conditions and to obtain the following information:

1. Bearing and seal heat rejection from each engine compartment
2. Oil consumption
3. Determination of complete lubrication system adequacy and compatibility with the engine and other systems, particularly the fuel pumping and control system.
4. Scavenge oil flows from each bearing compartment
5. Overall heat rejection of the lubrication system
6. Oil cooler efficiency
7. Determination of amounts of entrained air in the oil at various locations in the lubrication system.

Lubrication system monitoring and oil sampling procedures will be established and maintained on the Phase III development engines and the oil system rig to provide data to identify potential mechanical problems and to extend the oil use time by eliminating fixed drain periods for the JTF17 engines. To monitor the lubricant in the lubrication system, the scavenge system magnetic chip detectors will be inspected periodically for foreign particles. Microscopic and spectrographic analysis of the particles will then be made to pinpoint the source of the particles and the extent of the problem. In order not to necessitate the establishment of engine fixed oil drains, periodic oil samples from the oil system rig and development engines will be taken and analyzed for change in viscosity, neutralization number, and metal content. The oil sample analysis will be correlated with the Lube-Rater tester electrical conductivity values of the oil samples. (The Lube-Rater oil conductivity tester and the Pratt & Whitney Aircraft developed Constant Oil Monitoring System are presently being used by 26 world airlines). The data obtained from these monitoring and oil sample procedures will be analyzed to establish service limits of the engine lubricants.

The flight line serviceability of the lubrication system, including the oil tank, chip detectors, oil pumps, oil filters, and fuel-oil coolers will be developed and evaluated on the development engines and on the oil system and gearbox rig. Improvements will be made where necessary to make the JTF17 engine easily maintainable.

e. Certification Testing

All lubrication systems components will be qualified on JTF17 certification test engines.

2. Lines and Fittings

a. Introduction

The JTF17 fuel, lube, hydraulic, and pneumatic components are integrated by the engine lines and fittings, which consist of tubing, tubing connectors and tubing supports, in a manner that permits the engine to be controlled by a single power lever as shown schematically in Volume III, Report B, Section II-I. The working fluids are engine fuel for the gas generator and the duct heater fuel systems, engine fuel for the hydraulic system, oil for the engine lubrication system, and air as required by pneumatic components or the airframe environmental control system. The engine fuel system supplies fuel to the hydraulic system which in turn recirculates fuel back to the engine fuel system. The use of fuel as the working fluid in the hydraulic system eliminates the need for the engine to carry an independent hydraulic oil system; this concept was introduced and developed for the high performance, Mach 3+ J58 engine.

To permit and maintain operation of the JTF17 engine at any thrust setting for any flight condition, the engine tubing must safely carry the working fluids to several locations on the engine through a wide range of operational pressures and temperatures. To accomplish this task, the engine tubing ranges in diameter from 5/16 to 2-1/2 inches with wall thicknesses that vary from 0.035 to 0.065 inches. Mechanical tube connectors are utilized to provide quick installation, servicing and removal of the components, and to provide ease of engine disassembly and overhaul with high reliability and no leaks.

b. State-of-the-Art

The development and flight experience obtained from the J58 engine program have illustrated that the integrity of the engine tubing system is essential to reliable operation of a high performance, high Mach number jet engine. The JTF17 engine tubing, tube connectors, and tubing supports are based on design criteria established by the J58 engine as described in Volume III, Report B, Section II-I.

During the initial J58 engine development, completely brazed tubing connectors were utilized at engine assembly but were found to be unsatisfactory. The problems encountered were nonuniform braze coverage, lack of adhesion, and stress risers that reduced tube fatigue life and led to early failure. In addition, contamination, installation accessibility, maintenance procedures, overhaul times, and X-ray and pressure test

inspection techniques at engine assembly were unacceptable.

Mechanical connectors, with conical or K-type metal seals, replaced brazed connectors on the J58 engine to provide a high temperature leak-tight connector which permits quick installation, servicing, and removal of the components. However, leakage problems were still evident through the brazed joint between the tube and the ferrule. An integral tube connector that eliminates this brazed joint was developed by P&WA and has provided excellent service on the J58 engine and during the Phase II-C program.

(1) Tubing Materials

Tubing materials, AISI type 347 stainless steel (PWA 770), Inconel and Inconel X, are currently used on the J58 and TF30 engines, and will be utilized on the early JTF17 development engines during Phase III. These materials have demonstrated satisfactory service life and compatibility with fuel and oil while accumulating over 2?,000 hours of engine operation, which includes over 10 Mach 3 mission cycle 150-hour endurance tests, and during extensive flight test.

Investigation of titanium tubing for use in the JTF17 engine tubing system to save weight was initiated during Phase II-C and will be continued in Phase III. Commercially pure titanium tubing, grade A-40, and alloy tubing 3AL-2.5 V have been procured and successfully upset for the integral connector. Procurement of alloy 6AL-4 V is in process. The commercially pure tubing has thus far exhibited unacceptably low vibratory fatigue life when subjected to JTF17 engine environmental conditions. Insufficient test data for the 3AL-2.5 V alloy has been obtained to evaluate the material as tubing. Wolverine Tube of Calunet and Hecla, Inc., is developing titanium tubing under Contract AF 33(615)-3089 and Superior Tube Company and Reactive Metals are conducting in-house studies of titanium tubing. In addition, the Boeing Company is testing titanium under a government contract. The results of these programs will be monitored throughout Phase II-C and Phase III and utilized as applicable.

Titanium tubing will be procured and developed for the JTF17 engine during Phase III.

(2) Mechanical Connectors

The integral tube connector will be fully utilized on JTF17 tubing. It is easily produced by hot upsetting parent tube material, as shown in figure 166, into a head from which the required connector configuration is machined, as shown in figure 167. The upset and machining process consistently yields high quality integral connectors as compared to the occasional unsatisfactory joints which occur with brazed joints despite the most elaborate brazing and inspection methods. Fabrication costs of integral connector tubing is less than brazed connector tubing. In addition, the vibratory fatigue strength of the integral connector is 25% better than that of the brazed joint. Figure 168 and table 18 show the evolution of connectors and fatigue test results of brazed and integral connectors, respectively.

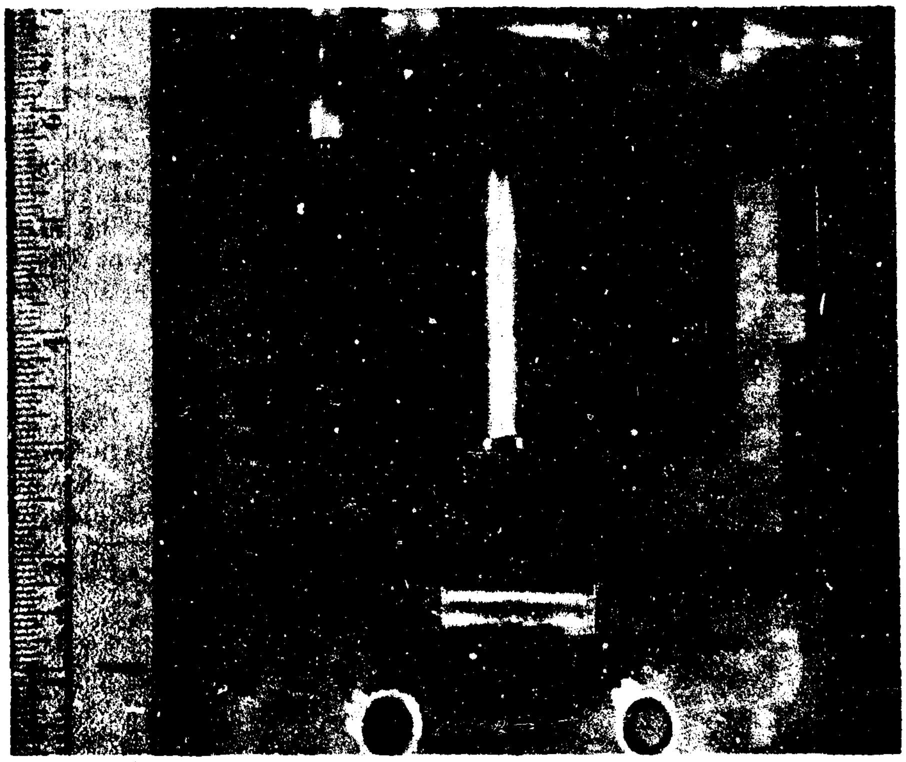


Figure 166. Integral Connector Produced by Hot Upsetting Parent Tube Material — FC 6596 EII

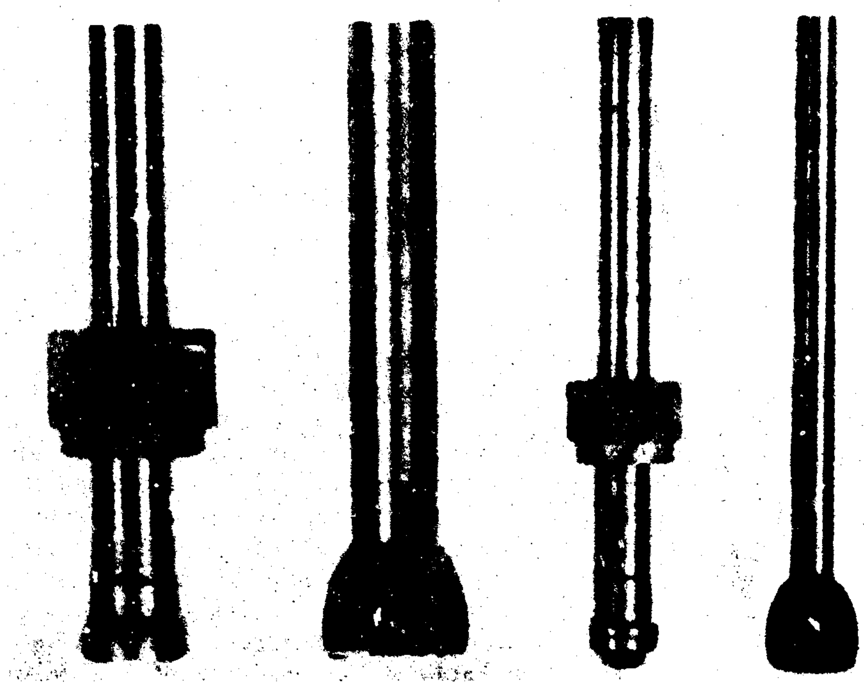


Figure 167. Integral Connector Configuration, J58 Tubing — FE 56694 EII

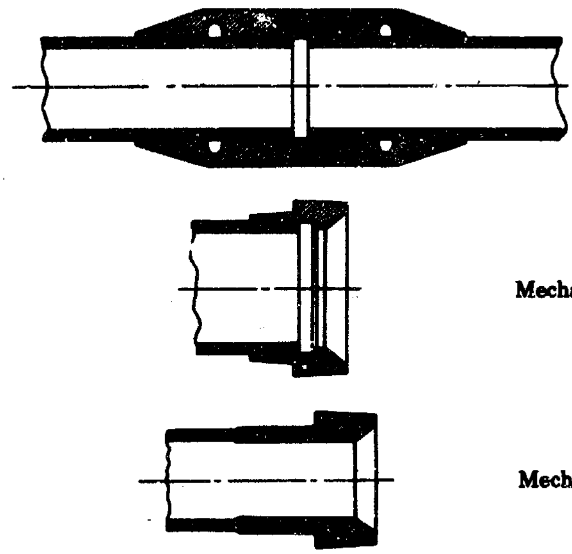


Figure 168. Evolution of Integral Connector

FD 16818
EII

Table 18. Fatigue Test Results, Brazed and Integral Connectors

Test Conditions:

Tube Material - PWA 770 (AISI 347)
Temperature - 450°F
Pressure, Internal - 4500 psi
Number of Cycles - 10^7

Tube Size - in.	Brazed Connector - psi	Integral Connector - psi
0.375	22,500	32,500
0.500	20,000	30,000
0.750	20,000	25,000*

*Maximum Stress Level Tested.

Because the JTF17 engine fuel and hydraulic systems normally operate at a pressure of 1650 psi or less as compared to 2500 psi for the J58, use of the successful J58 conical and reusable K-type metal seals ensures a reliable, leak-proof, easily maintained mechanical connector on the JTF17 engine. Figure 169 and table 19 illustrate the JTF17 mechanical connector seal configurations and the J58 engine experience to date.

Mating component connectors are mechanical tube-to-boss adapters utilizing K-seals. These adapters are easily replaced if worn or damaged, thus eliminating repair or scrappage of expensive component housings, as shown in figure 170.

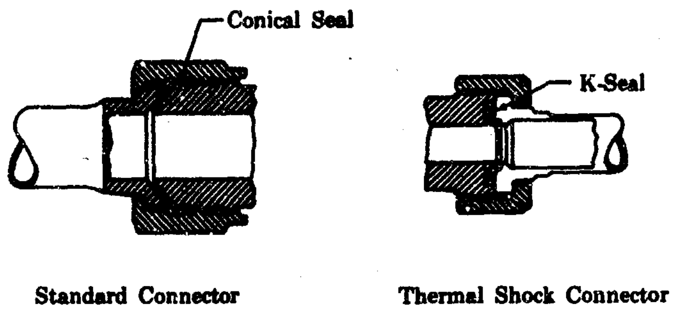


Figure 169. Mechanical Connectors FD 16820 EII

Table 19. Engine Experience, Mechanical Connectors

		Hours
1.	Total Time	22476
2.	Total Time, Integral	5208
3.	Total Time Above 400°F, T_{T2},	5870
4.	Total Time above 400°F, T_{T2}, Integral	2147
5.	Total Hot Fuel Time Above 200°F	3297
6.	Total Hot Fuel Time Above 200°F, Integral	1353

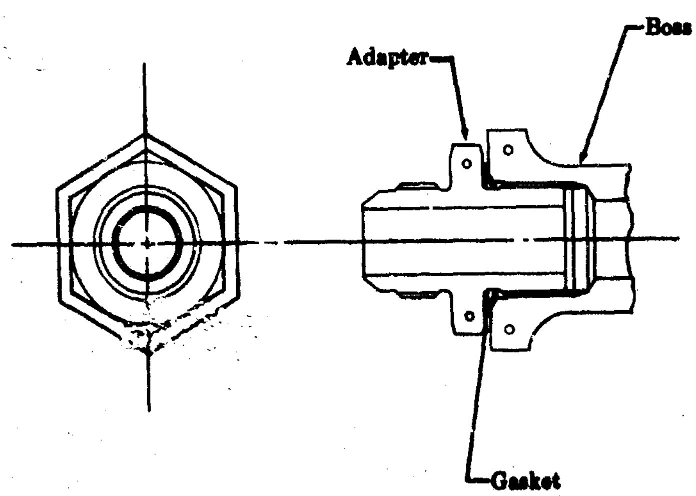


Figure 170. Boss-to-Adapter Joint FD 12337 EII

(3) Tubing Supports

Tubing supports have proved to be another important member of a durable tubing system. The tube standoff will consist of a three-piece, loose cover that is supported by small tee-shaped collars attached to the tube. This configuration permits the tube to flex through the standoff instead of forming a rigid local tube section, eliminates clamp wear on the tube, and damps the tube vibrations by friction between the covers and collars. The elements of this standoff are inexpensive and easily replaceable.

The brackets are designed to be stiff in all directions, except where thermal expansion requires tube and bracket deflections to minimize stresses. The evolution of the standoff configuration described above is shown in figure 171.

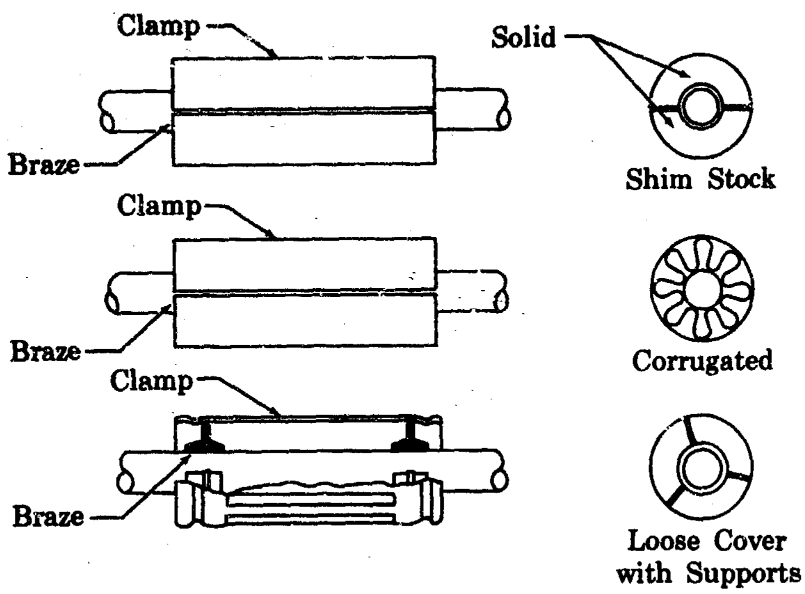


Figure 171. Evolution of Standoff FD 17000 EII

4. Tube Routing and Support Design Techniques

Early in the development phase of the J58 program, it became evident that the simple method of determining the routing of a tube from point-to-point based primarily on envelope considerations, was not satisfactory for high performance, high Mach number engines. Exacting design criteria were required for tube routing and support to reduce stresses under all anticipated operating conditions. To increase engine reliability and to reduce the overall plumbing design time, computer programs incorporating these design criteria for tubing were developed. The computer programs provide a quick and accurate means to route tubes for the best compromise of length, weight, and flexibility to keep static stresses low and uniform while ensuring a satisfactory clearance envelope. The program calculates the stress at any point in the tube with any desired combination of support points. The program also calculates the relative displacement of the tube at the bracket attachment, permitting the bracket to be properly designed to accommodate thermal expansion in a direction to minimize stresses. Fixed brackets to eliminate resonant vibrations are positioned at points where no thermal growth movement is encountered. Figure 172 summarizes the design procedure.

This development experience and design technique, along with actual experience on the J58 engine installation, will be utilized in the JTF17 design. By using integral connectors that have consistently proved reliable, and by the proper routing and bracketing of tubing based on service-proved design criteria, the reliability of static seals and tubing on the JTF17 engine can be equal to that of rotating disks.

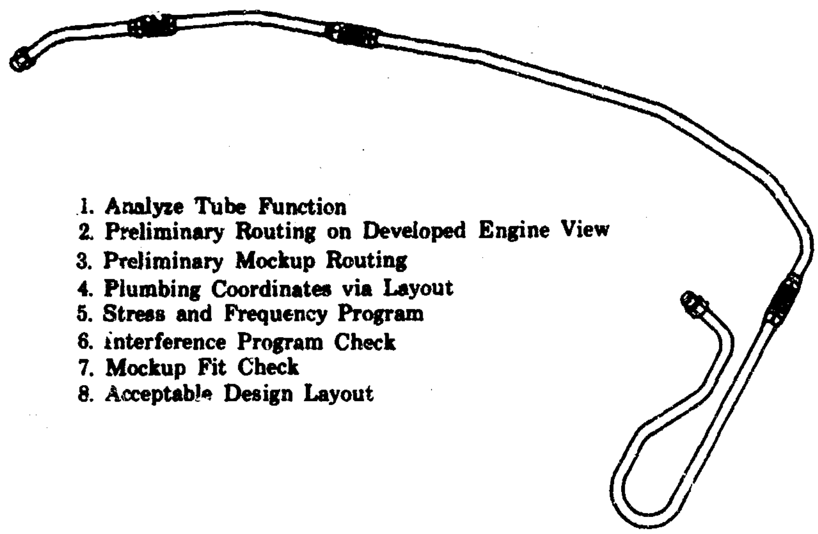


Figure 172. P&WA Tube Design Process FD 17001 EII

The test program objectives, facilities and equipment, the test program, acceptance criteria, and usage schedule are described in the following paragraphs.

c. Test Program Objectives

The objectives of the test program are the continuation of integral connector development with PWA 770 and PWA 1060 materials, the development of titanium tubing, the development of lightweight leak-proof mechanical connectors which are compatible with titanium tubing, the determination of suitable tubing supports, and the determination of tubing configurations that permit quick installation, servicing, and removal of the components.

The development of titanium tubing will constitute a major portion of the Phase III development effort for lines and fittings and will include work on upset forming, welding, bending, vibratory tests, salt water testing, fuel and oil compatibility tests, heat transfer tests, determination of suitable mechanical connectors, and engine tests.

d. Facilities and Equipment

The facilities and equipment required to perform the above testing consists of a machine for hot upsetting of the tubing, automatic welding equipment for tubing, electro-magnetic and MB type vibration shakers, materials properties testing equipment, heat transfer test rigs, and pressure and temperature monitoring equipment. Because of the multipurpose of such equipment, the status of available equipment and new equipment that will be required are presented in the Manufacturing Techniques and Materials Section.

e. Test Program

(1) Fuel and Oil System Plumbing

(a) Materials Laboratory Programs

Materials Development Laboratory programs relating to titanium tubing will include the following:

1. Evaluation of mechanical properties of various candidate materials
2. Fabrication investigations, including upset forming, welding, braze compatibility for standoffs and bending
3. Vibratory fatigue under simulated JTF17 operational and environmental conditions
4. Corrosion testing with salt water, fuel, oil, and bleed air
5. Heat transfer testing
6. Tubing connectors will be developed in conjunction with integral connector and welded configurations suitable for titanium tubing. The AN or K-seal types are preferred but will be modified or changed as determined by vibratory, pressure and temperature, and thermal shock tests to obtain a leak-proof mechanical joint. Metal seals that are compatible with the selected titanium material will be developed. Coatings, platings, and/or anti-galling compounds will be employed where required; possible lubricants are Fel-pro C.300 and Lubeco No. 2123.

This testing in the Materials Development Laboratory to evaluate titanium alloy tubing and related mechanical connectors for the JTF17 engine suitability will require an estimated 1200 tests and accumulate 27,600 test hours over a period of approximately 3 years.

The results of these programs will be used to define the titanium alloy tubing and the mechanical connectors for engine test of the plumbing system.

(b) Component and Engine Test Program

Plumbing system tubes will be instrumented for engine test to confirm the tubing design criteria. Thermal and vibratory stresses, the effect of stand-off spacing, and the effect of engine vibration and fuel and oil system pressure fluctuations will be evaluated during bench and engine tests.

A complete engine control system bench test rig will permit bench evaluation of engine plumbing during Phase III.

(2) Pneumatic System Tubing

Cabin air bleed manifold tubing, duct heater turbopump air supply tubing, and bearing compartment labyrinth seal vent lines will incorporate two laminated bellows in each tube. These bellows will permit axial and radial thermal growth. The bellows spring rate, and the close-tolerance slip joint between the centertube ball ends and the end tube sections provide vibratory damping of the bellows-centertube section.

(a) Vibration Testing

These tubes will be vibration tested on a shaker table to determine the natural frequency and life of the bellows, and to develop the required wear capability in the ball-end joints.

(b) Engine Testing

Pneumatic system tubing will be instrumented and monitored during engine test to determine the vibration and wear characteristics of the tubing during engine operation. Cabin bleed air will be sampled to substantiate that the levels of contamination are within the engine specification.

f. Acceptance Criteria

The acceptance criteria of the engine plumbing shall be:

1. That the raw material conforms to its material specification and to the following nondestructive tests; visual for surface defects, eddy-current, ultrasonic, and fluorescent penetrant as applied to ensure the use of defect-free material.

2. That the finished engine tubing shall meet the inspection standards established for x-ray, fluorescent penetrant, pressure test, dimensional, and visual for surface defects caused by handling.

g. Usage Schedule

The number of plumbing sets required through Phase III is 48 to be delivered as follows:

1. 1967 - 13 sets
2. 1968 - 18 sets
3. 1969 - 12 sets
4. 1970 - 5 sets

These data are presented in figure 173.

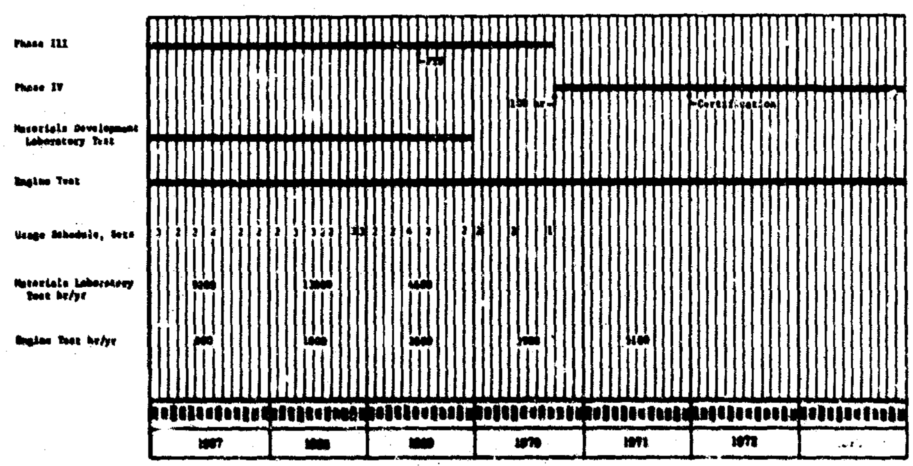


Figure 173. Proposed Development Plan - Lines and Fittings

FD 17741
EII

3. FUELS

a. Introduction

The fuel selected for the prototype JTF17 engine is currently-available aviation kerosene. The engine system has been designed to avoid the problems and costs associated with special fuel and handling problems such as those demonstrated by the JP-6 requirement and the nitrogen purging necessary for the B70 prior to refueling the aircraft. The SST fuel research program sponsored by the Federal Aviation Agency, with support and direction provided by the FAA SST industry advisory group and the CRC group on supersonic transport fuels and related equipment, has increased the general understanding of the fuel problems in the SST and their relationship to small-scale test devices. The consequence of using marginal fuels as measured in the ASTM-CRC coker was illustrated by the relative performance of the fuels in the test rig.

P&WA experience with current commercial engines having overhaul periods of up to 8000 hours and an understanding of these engine systems provide a basis for establishing maximum fuel system temperatures and the fuels required for the JTF17 engine. Phase II domestic fuel quality surveys and coordination with major fuel suppliers have provided an indication of the availability of the selected fuels. A program now in progress will provide a world-wide quality survey. This program will carry into Phase III and is a combined effort between a fuel supplier, the major airlines, and Pratt & Whitney Aircraft. Additional knowledge has been obtained during Phase II-C concerning the testing of lubricity and the effect of oxygen on thermal stability. Coordination of systems and fuel temperature requirements with the airframe has also been provided to maintain an economical fuel requirement that is compatible with both the engine and the airframe. Evaluation of lubricity test methods will continue in Phase III along with design coordination of engine system heat rejection requirements and airframe requirements. Additional information on the Phase II-C program results and a detailed description of the engine system requirements are supplied in Vol. III, Report B, Section III. Coordination will be continued with the major fuel suppliers to ensure that the prototype engine fuel requirements remain compatible with the availability of the fuel. Tests will be combined with the primary combustor component development program by running hot fuel through primary combustor nozzles in a combustor segment rig to substantiate the satisfactory performance of the fuel at maximum temperature.

The laboratory fuel testing program is outlined in this section, and the facilities are described to show that the Florida Research and Development Center is equipped to support the requirements of a fuel program to develop the JTF17 for economical operation in the SST.

b. Fuels Selected and Test Program Objectives

The JTF17 may be operated with PWA 522 fuel (excluding Type B aviation Kerosene) or it may be operated with PWA 553 fuel to a higher fuel inlet temperature limit. The PWA 522 type fuel (Jet A and Jet A-1 as defined by ASTM D 1655 test method) is the fuel used in current commercial engines. Fuel inlet temperature limits to the engine are based on not exceeding an engine internal maximum fuel temperature of 300°F, which is the same

as experienced in current PWA commercial engines. The JTF17 fuel system has been designed for maximum use of the fuel heat sink available, and the fuel temperature limits at the pump inlet have been increased more than 100°F over current engines such as the JT3, JT4, JT3D, & JT8D The limits for the JTF17 are a function of the total fuel flow and the operating conditions. For a complete review of this system and the factors effecting the temperature limits, refer to Vol III., Report B, Section III.

PWA 533 fuel is also a currently available aviation kerosene and the 1964 fuel quality survey showed that approximately 90% of the samples taken at domestic airports would meet the requirements of this specification. The engine fuel inlet temperature limits are increased 50°F with PWA 533. This fuel specification is the same as the specification for all other current commercial PWA engines, except for a 50°F increase in the thermal stability requirement. This change is from 300/400 to 350/450 as measured in the standard ASTM-CRC coker. No new test methods are required. The PWA 533 fuel specification is tabulated in Vol. III, Report B, Section IV.

The program to substantiate the suitability of the selected fuels will include laboratory tests, component rig tests, and engine tests. The objectives of these tests will include the development of an improved understanding of the fuel characteristics and the investigation of more definitive test methods to evaluate the fuel properties. The thermal pre-stress effects (for example, fuel heating in the airframe tanks and systems) will be investigated in small-scale rigs to evaluate the reaction on the fuel delivered to the engine inlet. Evaluation of small-scale fuel thermal stability test devices will be continued to establish a relationship with the full-scale component and engine results.

c. Test Programs

(1) Laboratory Testing

The major laboratory program will be the monitoring of fuel properties to ensure that the current levels do not change unexpectedly and affect other component programs. A fuel contamination problem could occur anywhere between the refinery and the test stand. Both engine tests and component tests could be set back if a failure to perform satisfactorily were caused by an unrecognized fuel contamination problem. Shipping and storage controls are described in Vol. III, Report B, Section III.

The laboratory tests scheduled for the JTF17 fuel program are outlined in paragraph e, following, which describes the complete fuel inspection capability of the Materials Laboratory at the Florida Research and Development Center.

(2) Fuel/Engine Fuel System Compatibility Testing

The suitability of the current quality aviation kerosene to operate in the environment of the JTF17 engine will be demonstrated on the primary combustor test rig described in the Component Test Section IIB3. This testing will be accomplished as an integrated part of the primary combustor program. The first and most significant of these tests will be endurance programs run in a two-nozzle segment at the maximum fuel temperature expected to be encountered at the end of the cruise. By running long

endurance times in this rig, the high durability and low maintenance characteristics of this fuel nozzle concept will be demonstrated. Shorter tests of the same nature at higher-than-expected fuel temperatures will be run to confirm the reliability established by this nozzle concept in J58 testing. Although maintenance requirements will increase in relationship to the severity of the temperature conditions, these tests will substantiate that the engine will continue to perform satisfactorily even if airframe fuel handling difficulties should result in exceeding the specified fuel inlet temperature limits.

(3) Contaminated Fuel Test Program

The ability of the engine to operate with contaminated fuel is described in the Controls and Accessories Section IIC. The concept of the prototype fuel nozzle design includes constant flushing of all areas to prevent stagnation and accumulation of carbon deposits. This same feature will permit the very fine contamination particles to flush through the nozzle, because the smallest orifice is 0.018 inch in diameter. The screen in the nozzle and support assembly is intended only to protect the nozzle against large particles accidentally introduced into the system when any of the plumbing is open for maintenance or assembly work. This screen will pass particles as large as 0.012 inch to prevent it from becoming plugged by very fine fuel contamination particles which the nozzle is capable of passing. The ability of the nozzle to operate on contaminated fuel as described will be substantiated by endurance tests run in the two-nozzle segment rig.

(4) Fuel Test Programs on JTF17 Engines

The primary combustor segment rig tests will only provide previews of the fuel compatibility to the engine system. The full-scale engine altitude endurance cycles run with heated fuel will be the actual demonstration of the fuel suitability. This is the only location where all of the many interacting systems and environmental conditions can be combined. The altitude engine tests prior to the endurance programs will provide data to substantiate the calculated conditions run on the small segment rigs. When changing conditions warrant, the rig operating conditions will be revised to the demonstrated engine conditions.

Engine testing will be conducted with the airframe fuel system components to verify dynamic compatibility of the airframe and engine fuel systems. For additional information on this program, refer to Section III (Engine Test).

(5) Fuel Availability (Engine/Airframe/Fuel Supplier Coordination)

The continued availability of the current quality aviation kerosene when the SST becomes operational will be part of a coordinated program with the oil companies in cooperation with the airframe contractor. For further comments on the Phase III programs with oil company coordination and availability surveys, refer to Vol. III, Report B, Section IV.

d. Fuel Test Rigs

The test rigs for the laboratory programs are described in detail in Volume V, Report B (Facilities Program), which provides a complete review of the fuel inspection capability at the Florida Research and Development Center.

A fuel lubricity test method will be investigated on currently available equipment. Standard high pressure pumps are used for these accelerated wear tests as reviewed in Vol. III, Report B, Section IV.

The segment rigs, which will demonstrate the suitability of the selected fuels and operate at the maximum temperatures expected in the JTF17 engine, are described in Section IIB-3 of this report. This includes the turbine high spool rig (the high rotor section of the engine).

Each run of an experimental JTF17 engine in the Phase III program will provide additional substantiating evidence of the suitability of the fuel selected for the JTF17 engine.

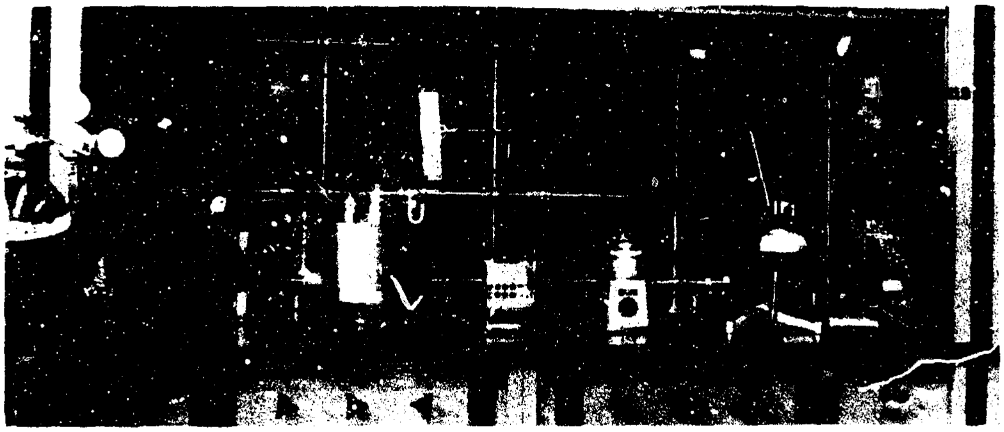
e. Test Facilities

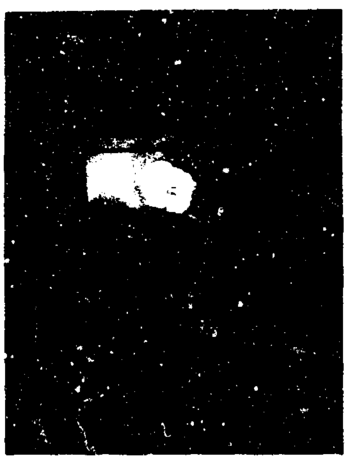
The Pratt & Whitney Aircraft Florida Research and Development Center has all facilities required for complete fuel inspection. Laboratory tests can be performed to determine the physical characteristics of fuel such as viscosity, distillation, specific gravity, flash point, and aeromatic content. In addition, the more complicated physical property and bench performance tests can be conducted. Standard testing equipment for measurement of viscosity at 100°F and 210°F, viscosity at low temperature, lamp hydrogen method, open cup flash point, closed cup flash point, Pensky-Martens flash point, micro balance and potential and existing gum apparatus are shown in figure 174.

Major equipment for fuel testing includes the ASTM-CRC fuel coker automatic unit (Model 03FC), the modified ASTM-CRC fuel coker, CRC research fuel coker (Model 01RFC), ASTM-CRC luminometer, precision heat of combustion apparatus, Ryder gear tester, CRC water separometer, modified bulk modulus apparatus, beta-ray hydrogen/carbon analyzer, vapor pressure indicators, infrared spectrophotometer. ultraviolet and near infrared ratio recording spectrophotometer, high temperature viscosity and mass spectrometer. A description of each of these items and the method of test follows:

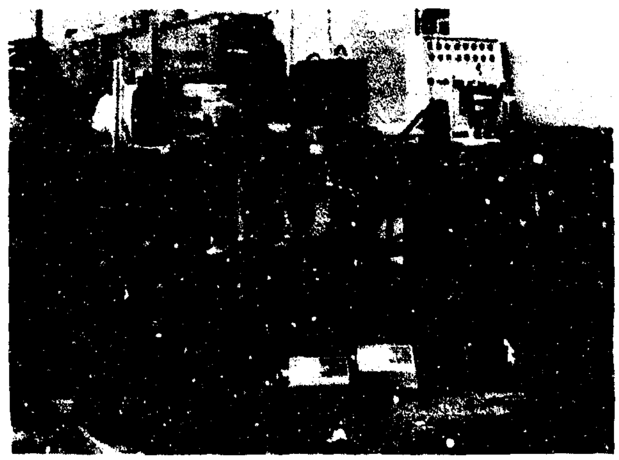
(1) ASTM-CRC Fuel Coker-Automatic Unit - (Model 03FC)

The automatic ASTM-CRC fuel coker Model 03FC is shown in figure 175 and illustrated schematically in figure 176. This unit incorporates devices for automatic control of preheater temperature, filter temperature, and fuel flow rates. It also includes provisions for continuous recording of pressure drop across the test filter. This equipment is used for the relative comparison of the thermal stability of fuels by rating the deposit characteristics on the wall of the preheater tube and by comparing the filter plugging characteristics over a period of 5 hours.

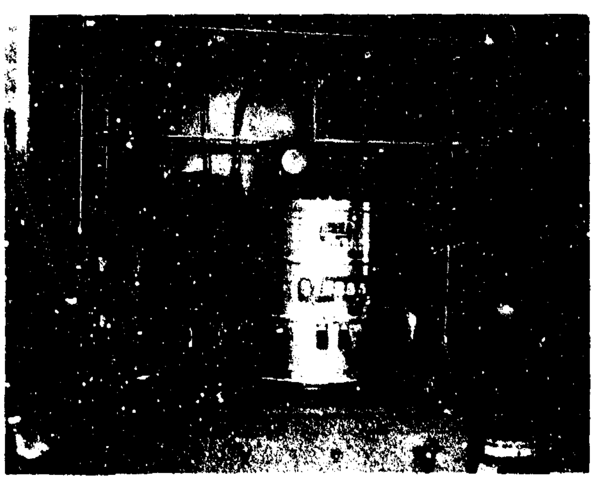




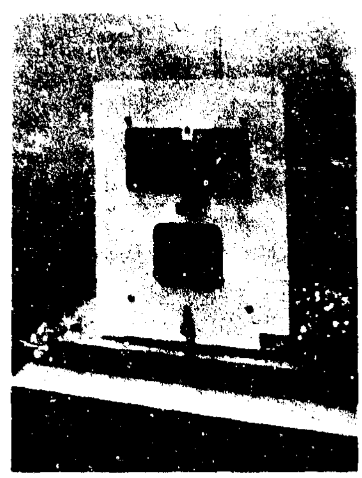
Low Temperature
Viscosity Apparatus



100° and 210°F Viscosity Apparatus



Potential and Existing Gum Apparatus



Micro Balance

Figure 174. Fuel Testing Equipment

FD 16492
EII

Figure 175. Modified Fuel Coker Reservoir Heating Section — FD 16792 EII

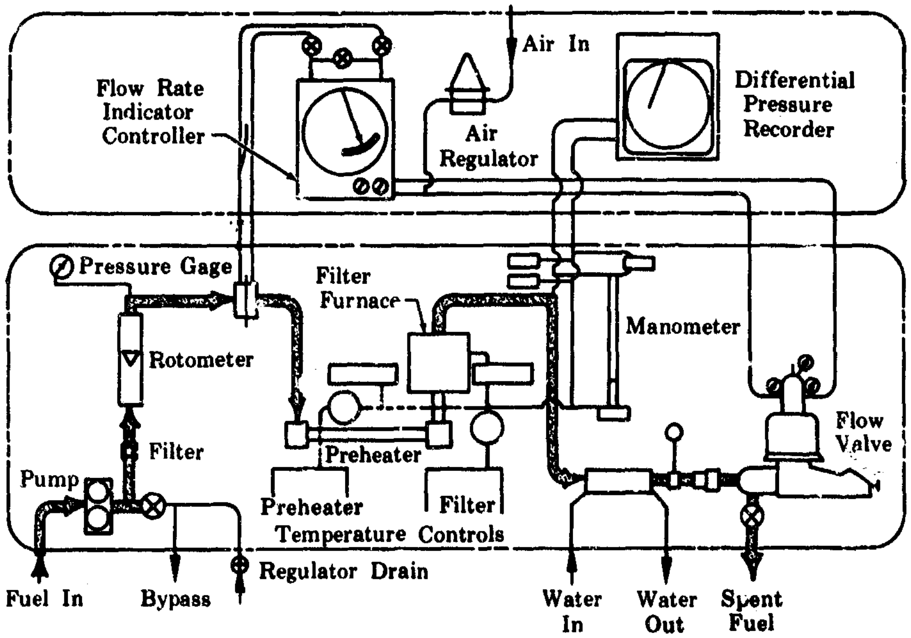


Figure 176. Schematic of ASTM-CRC Fuel Coker - Model 03FC — FD 16493 EII

The test fuel in pumped from a fuel reservoir at ambient temperature through a heated annular space. This space is formed by inserting a small aluminum tube inside a larger aluminum tube; the annular space being the area between the outer wall of the inner tube and the inner wall of the outer tube. Heating is accomplished by inserting a Calrod heater inside the inner tube. Fuel outlet temperature from the preheater is closely controlled by automatic temperature controllers. The

present limit for the preheater outlet temperature on this standard coker is 450°F with 6.0 lb/hr fuel flow. The fuel from the preheater outlet is passed through a sintered stainless steel filter immediately downstream of the preheater section. This filter is located in the center of the filter furnace, whose temperature is maintained 100°F higher than the preheated fuel. Fuels that are not normally stable under the selected operating temperatures leave deposits or stains on the preheater tube, or form particulate matter that is stopped by the filter. An observed pressure rise is measured by a mercury manometer located on the front of the fuel coker. Either or both of these effects may occur in any particular fuel. To pass this test the selected fuel must meet both the maximum deposit code on the preheater tube and the maximum filter pressure differential requirement selected by the fuel specification.

(2) Modified ASTM-CRC Fuel Coker

This equipment consists of a heated reservoir assembly where the fuel can be heated or subjected to thermal stress before the fuel is run through an ASTM-CRC Fuel Coker equipped with a modified insulated preheater section. This modified fuel coker reservoir heating section is shown in figure 175. The fuel is prestressed by heating it to a preselected temperature and holding this temperature for a predetermined time. At the end of this heating cycle, the fuel is cooled to room temperature by submerged cooling coils in the reservoir. The fuel is then passed through the modified preheater section of the ASTM-CRC Fuel Coker and on through the normal filter furnace assembly. The fuel flow rate when using the modified method is normally set at 2.5 lb/hr instead of 6.0 lb/hr flow rate which is the level for the standard fuel coker operation. This lower flow rate gives a higher residence time for the fuel in the preheater section. The results of this test are also judged by the preheater fuel deposits and the filter pressure drop.

(3) CRC Research Fuel Coker (Model 01RFC)

Figure 177 shows the CRC Research Fuel Coker in operation in the Materials Development Lab. The schematic of the research coker is shown in figure 178. This unit is based on the same components as the ASTM-CRC Fuel Coker but extends the test temperatures to approximately 800°F at 6.0 lb/hr fuel flow rate through the preheater section. The Research Fuel Coker is equipped with a heated reservoir assembly for prestressing the test fuel. The fuel is heated to the desired starting temperature, which may be considered as representative of the bulk fuel temperature prior to delivery to the engine. When the selected reservoir temperature is reached, fuel is pumped through the preheater and filter sections of the coker for 5 hours as in the standard coker tests. The performance of the fuel is again based on the deposit formation on the preheater tube and the filter pressure differential as in the standard coker tests. The heated reservoir cycle is a means of prestressing the fuel. This type of test may serve as a guide to the thermal stability of a fuel under the prolonged heating that it will encounter in an airframe flying at Mach 2.7 conditions. Both the modified ASTM-CRC Fuel Coker and the Research Fuel Coker can provide this means of prestress-testing of the fuel. However, the Research Fuel Coker can complete the test in a

shorter period of time, because the cooled down cycle, which is not representative of our operating conditions, is eliminated. The Research Coker will also provide a better comparison with the standard coker for the effect of the prestressing because the flow rate in the preheater tube is the same as the standard coker, giving the same residence time for the fuel in the preheater section.

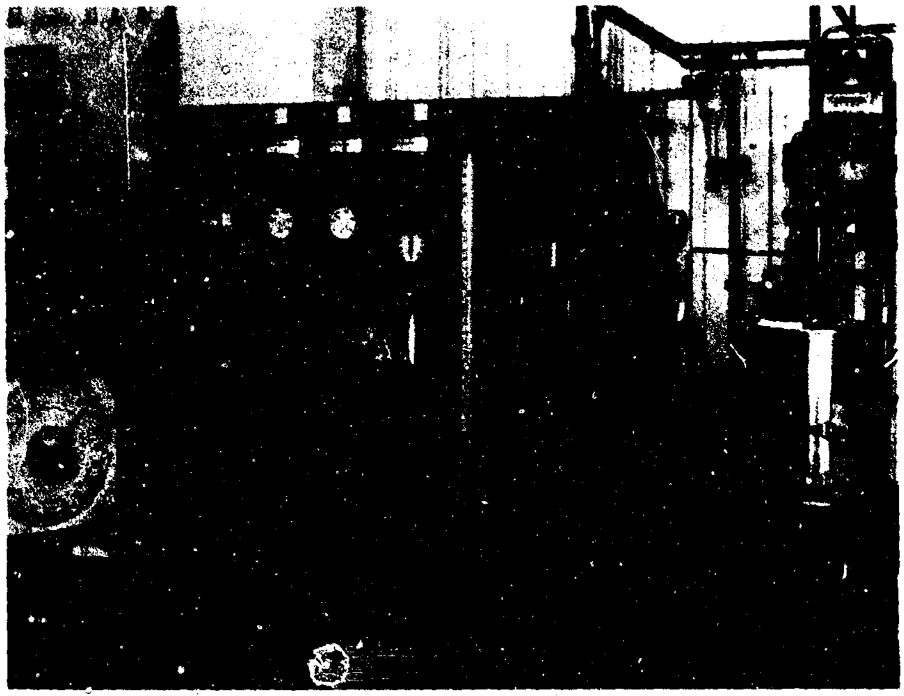


Figure 177. CRC Research Fuel Coker (Model 01RFC) FC 12533 EII

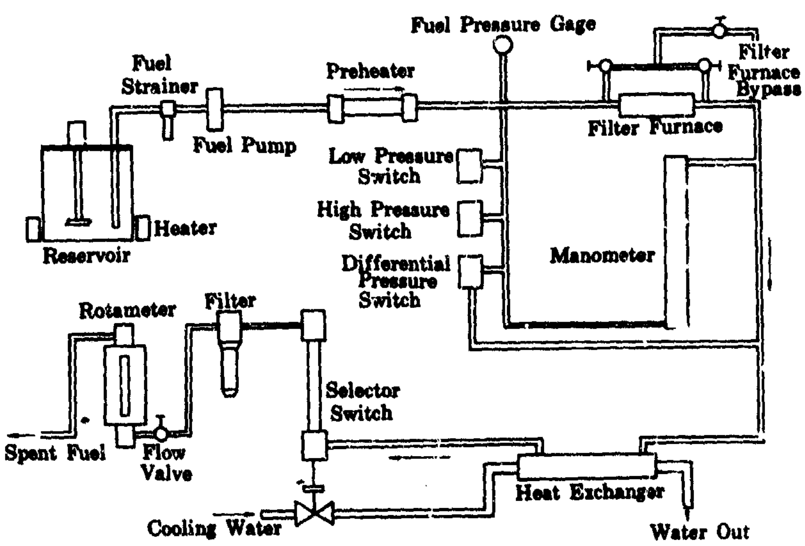


Figure 178. Schematic of CRC Research Fuel Coker FD 16494 EII

(4) ASTM-CRC Luminometer

Figure 179 shows the ASTM-CRC Luminometer. A schematic of the system is shown in figure 180. The Luminometer Number is a measure of the flame temperature at a fixed flame radiation in the green-yellow band of the visible spectrum, and can be correlated with the combustion characteristics of the fuel. The Luminometer Number of a fuel is determined by burning the fuel in the ASTM-CRC Luminometer lamp and obtaining a curve of flame radiation as measured by an optical filter and photo cell unit against the temperature rise across the burner measured by a thermocouple placed just above the flame. This temperature rise is compared to that obtained on a pair of reference fuels at a constant radiation level. The measurement of Fuel Luminometer Number determined as above has shown a correlation with exhaust smoke, combustor liner metal temperatures, and other fuel measurements relating to control of combustion quality. High luminometer number in a fuel indicates less radiation and, therefore, less unburned carbon in the combustor flame and less heat radiated to the combustor walls.

Figure 179. ASTM-CRC Luminometer

FC 12507
EII

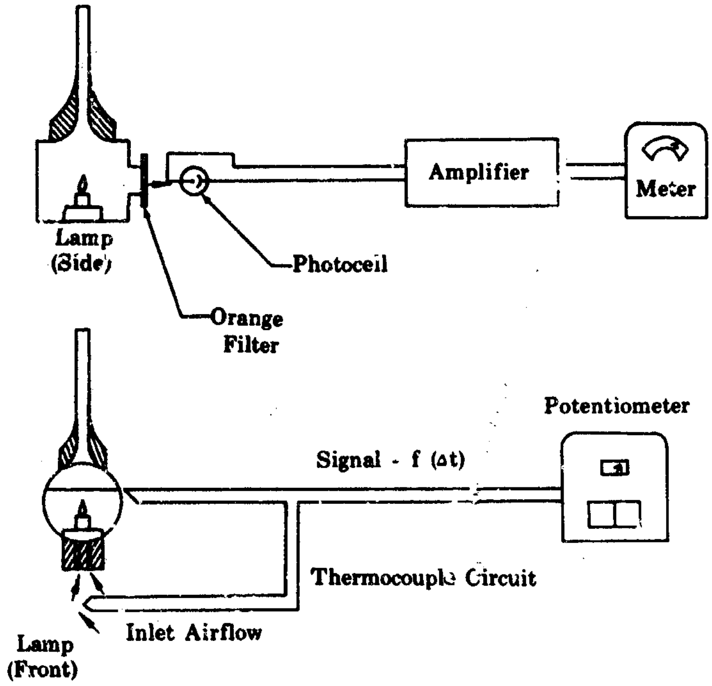


Figure 180. Schematic Diagram of ASTM-CRC Luminometer

FD 16495
EII

(5) Precision Heat of Combustion Apparatus

The precision heat of combustion apparatus was developed by Pratt & Whitney Aircraft. This method for measuring the heat of combustion is shown in figure 181. The apparatus consists of the Standard Parr adiabatic oxygen bomb calorimeter with the addition of thermistor temperature sensors connected to an automatic water bath controller. Temperature readout is accomplished by means of a platinum resistance thermometer in conjunction with a Mueller bridge and a galvanometer. Platinum sample cups and platinum ignition wire eliminate the use of the somewhat erroneous correction factor for heat of combustion of ignition wire. The use of these electronic temperature sensors and readouts, combined with the ability to detect sample weights to 1 microgram, enables the operator to measure the net heating value of the fuel with an accuracy of 20 Btu/lb in comparison to 55 Btu/lb by the standard ASTM method.

(6) Ryder Gear Tester

Ryder Gear Rig tests on fuel are reviewed in Volume III, Report B, Section IV. Phase II-C results indicate that this test is not as valuable for the fuel as it is for the oil, and new test methods will be investigated. However, the equipment is available, should a further review indicate a need for continued testing.

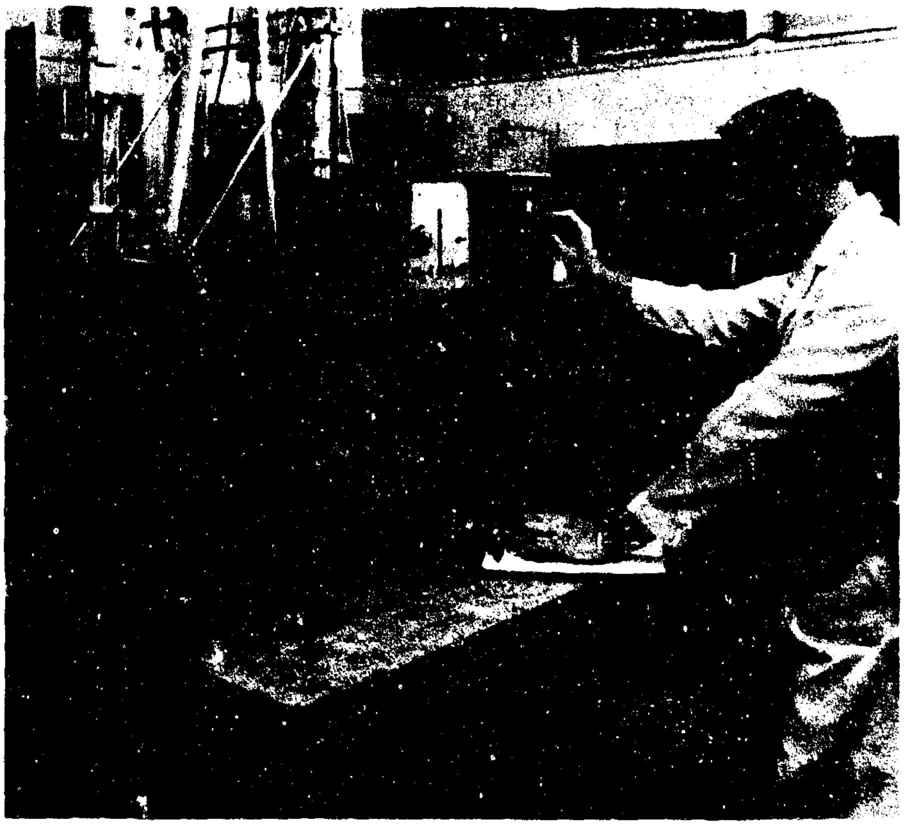


Figure 181. Precision Heat of Combustion Apparatus FC 12504
EII

The console and test section of the Ryder Gear Rig are shown in figures 182 and 183. This equipment determines the lubricity of lubricants, both organic and synthetic, used in jet engines. Lubricity is determined on a Ryder Gear Tester by the load, in pounds per inch of tooth width, that can be carried when the meshing involute gears are lubricated with the test fluid; the value is based on scuffing of 22.5% of the tooth area. This point is determined from a graph plotted by a series of points taken at different tooth loading and percent scuff measurements.

(7) CRC Water Separometer, Modified

The CRC Water Separometer and its schematic diagram are shown in figures 184 and 185. This method of test measures the water separation characteristics of fuels and fuel-additive compounds expressed in terms of Water Separation Index, Modified (WSIM). The numbers used to express the WSIM of a fuel vary from 0 to 100, the higher number being indicative of fuels relatively free of surfactant materials. Fuels containing very small amounts of surfactant materials precipitate or drop out dispersed or emulsified water much more readily than fuels with a low WSIM or fuels containing an appreciable amount of surfactants. This property of a fuel allowing quick dropout of a dispersed water enhances the value of the fuel in that only fuel is admitted to the jet engine rather than a fuel-water emulsion.

The Modified Water Separometer meter has three sections: emulsion preparation, where a small amount of water is introduced to 2000 ml of test fuel and emulsified by circulation at 80 psig with a gear pump; coalescer, where the fuel-water emulsion is metered at a set flow rate through a standardized Fiberglass coalescer; and an analysis section, where the effluent from the coalescer is analyzed for entrained water by light transmission.

Figure 182. Console of Ryder Gear Rig FC 12519 EII

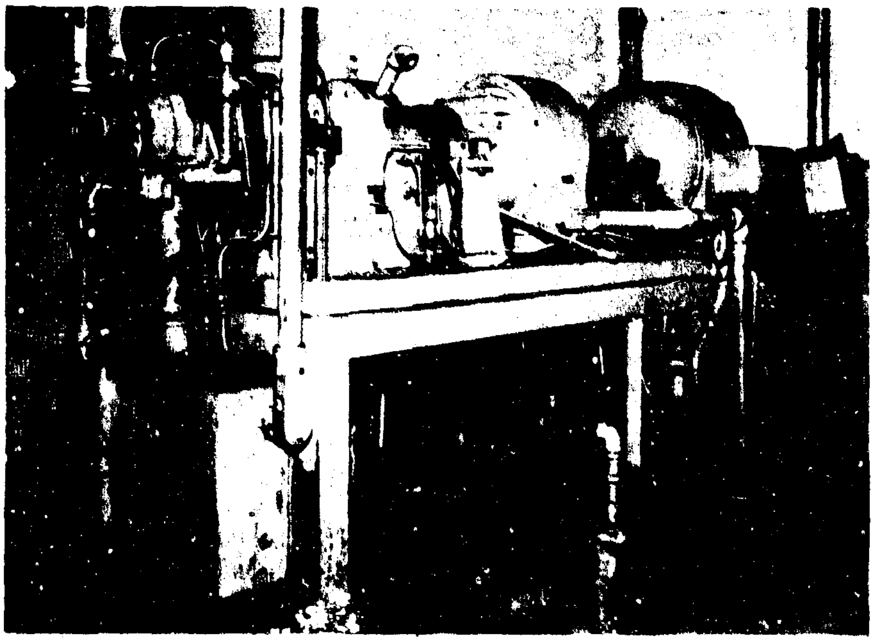


Figure 183. Test Section of Ryder Gear Rig FC 12518 EII

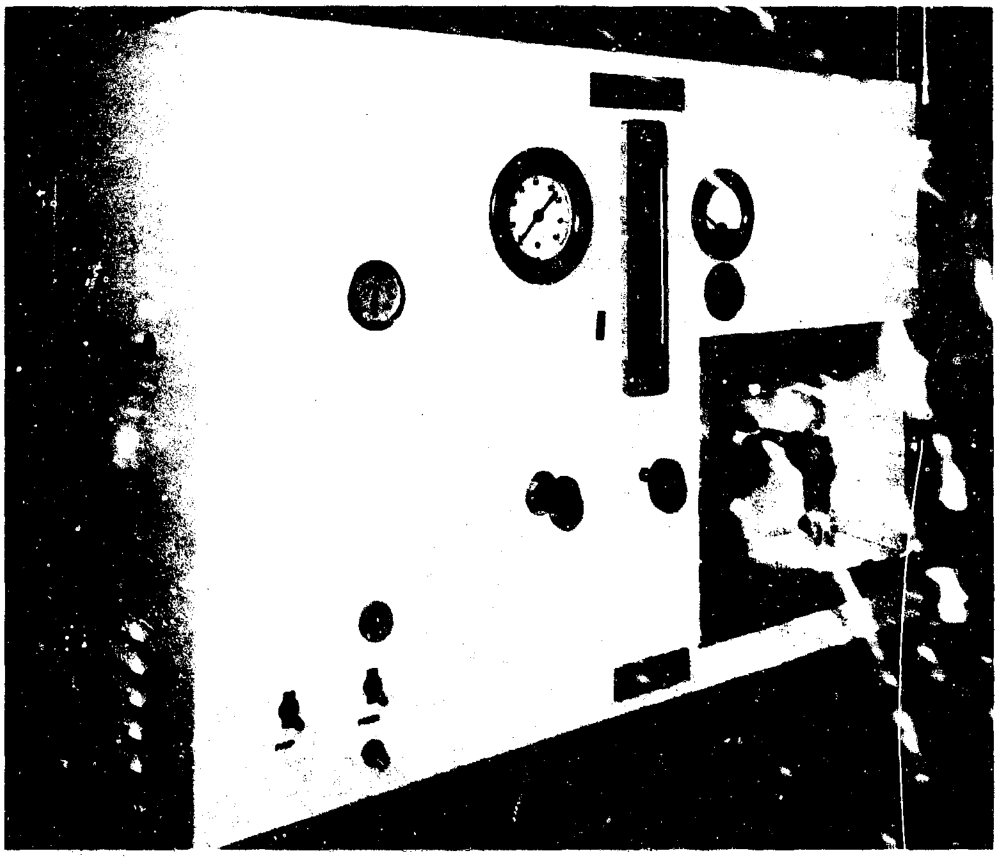


Figure 184. CRC Water Separometer FC 12506
EII

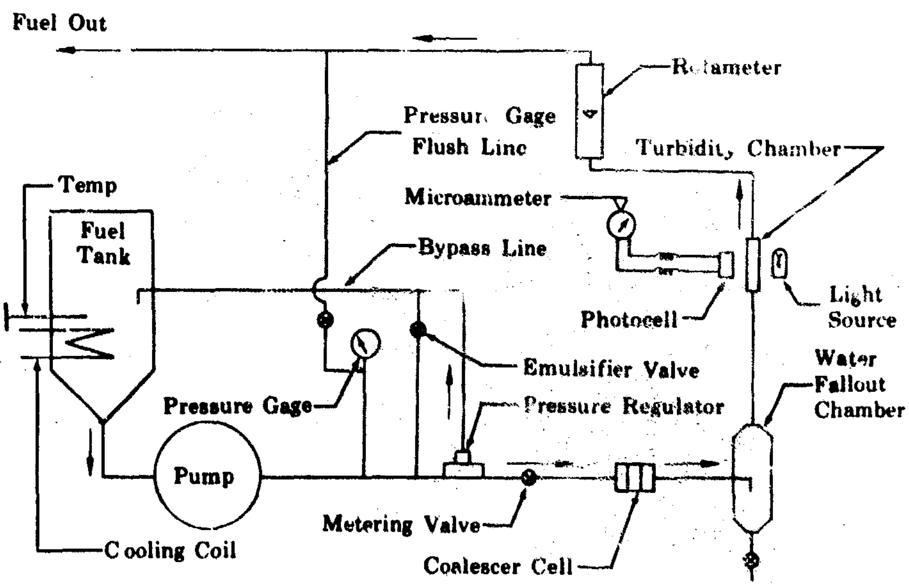


Figure 185. Schematic of Water Separometer FD 16496
EII

(8) Bulk Modulus Apparatus

The Bulk Modulus Apparatus and a schematic diagram are shown in figures 186 and 187. This equipment is used to establish the Isothermal Secant Bulk Modulus of fuels and oils currently being used in aircraft turbine engines. Bulk modulus is an important fluid property used in designing systems that use fluid to transmit force and control motion. Isothermal secant bulk modulus is defined as the total change in fluid pressure divided by the total change in fluid volume per unit initial volume under pressure at constant temperature. The Bulk Modulus Apparatus is composed of four sections: liquid reservoir, hydraulic pump, compression vessel, and a differential volume measuring vessel. In practice, the liquid is pumped from the reservoir to a compression vessel of known internal volume. Pressure is applied to a predetermined value, and the compression vessel inlet valve is then closed. When equilibrium temperature and pressure are obtained, the outlet valve is opened and the excess liquid allowed to drain into the measuring vessel. This excess liquid volume is used to determine the secant bulk modulus. The equipment as constructed at FRDC has operating parameters of ambient to 500°F and pressures from 500 psig to 5000 psig.

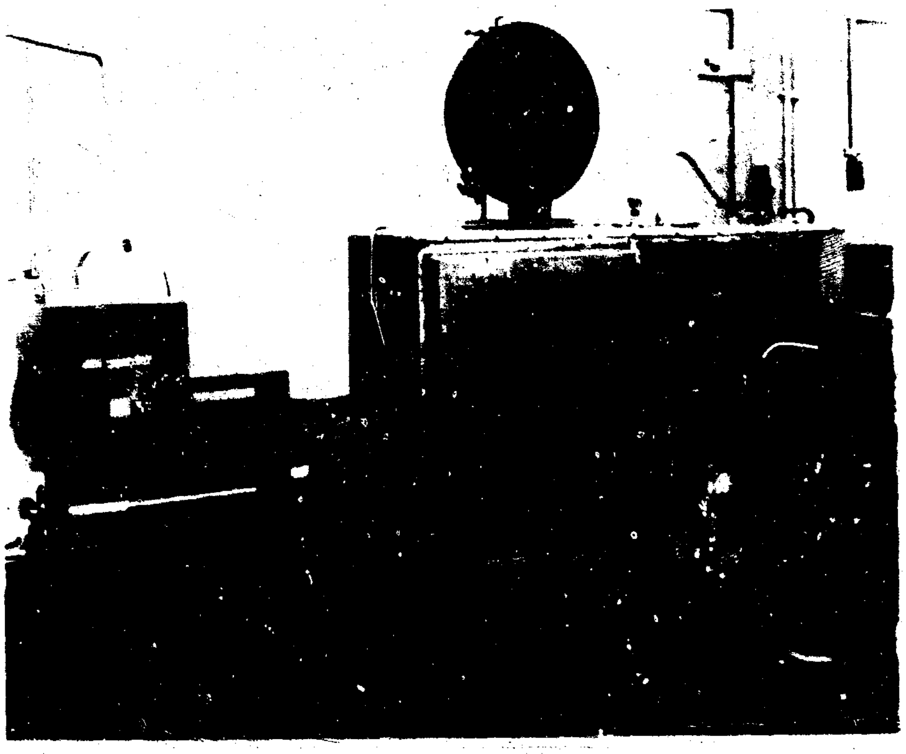


Figure 186. Bulk Modulus Apparatus

FC 12531
EII

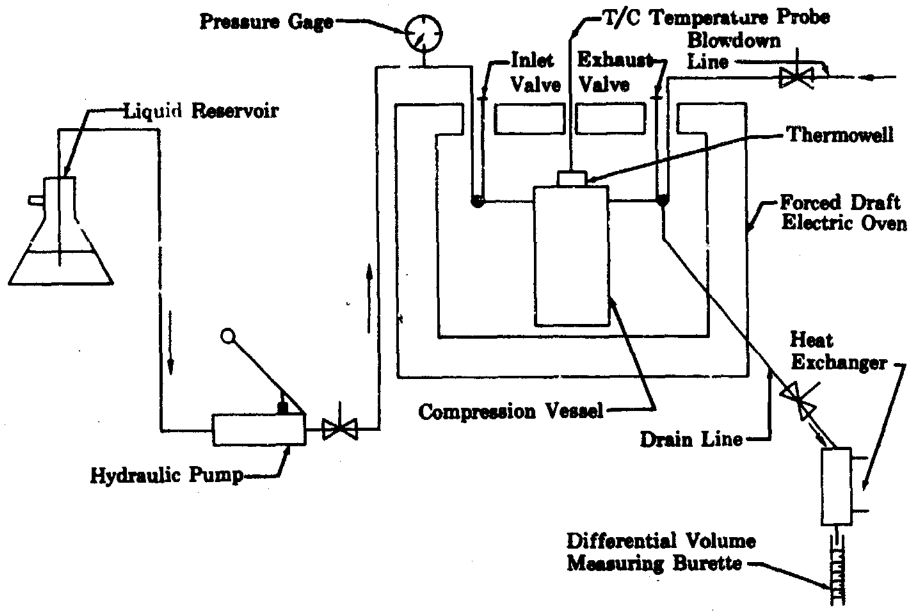


Figure 187. Schematic of Bulk Modulus Apparatus FD 16497 EII

(9) Beta-Ray H/C Analyzer

The Beta-Ray H/C Analyzer shown in figure 188 is used for determining the proportion of hydrogen to other elements in liquid samples. The analyzer is particularly adapted for establishing the ratio of hydrogen to carbon in liquid hydrocarbons and their mixtures. The usefulness of this device depends upon the fact that beta-ray absorption is an electron interaction. That is, the degree of absorption is directly related to the electron density of the sample. Since hydrogen has a greater number of electrons per gram of the element than any other element, the instrument can tell immediately the ratio of hydrogen to other elements present. In operation, pure hydrocarbon standards with known hydrogen content are used to calibrate the instrument, and plots are drawn graphically. The hydrogen content of test fuels absorption can then be determined from the relationship of their plots to the plots of the known standards. Knowledge of the hydrogen content of fuels is desirable in that the net heat of combustion of fuels can be calculated directly from the gross heat of combustion. To correlate data from the Beta-Ray H/C Analyzer, the Lamp Hydrogen Method, figure 188, or the Micro-Combustion Method are used.

(10) Vapor Pressure Indicators

Three types of vapor pressure measurements for hydrocarbon fuels, hydrocarbon oils, and synthetic oils are in common use at FRDC. For precise determination of vapor pressure in the temperature range from below ambient to 900°F, the Reflux Vapor Pressure Method, shown in figure 189, is used for fuels in the pressure range of 1.0 mm Hg to 760 mm Hg, which correlates with a starting liquid temperature of -40°F to the initial boiling temperature of the liquid. All pressure measurements taken on the Reflux Method are observed when liquid

temperature and vapor temperature are in equilibrium. The Reflux Method requires agitation of the test liquid during the duration of the test. This is accomplished by a magnetic stirrer. The other methods of determining vapor pressure are included in the section on Lubricating Oil Test Facilities.

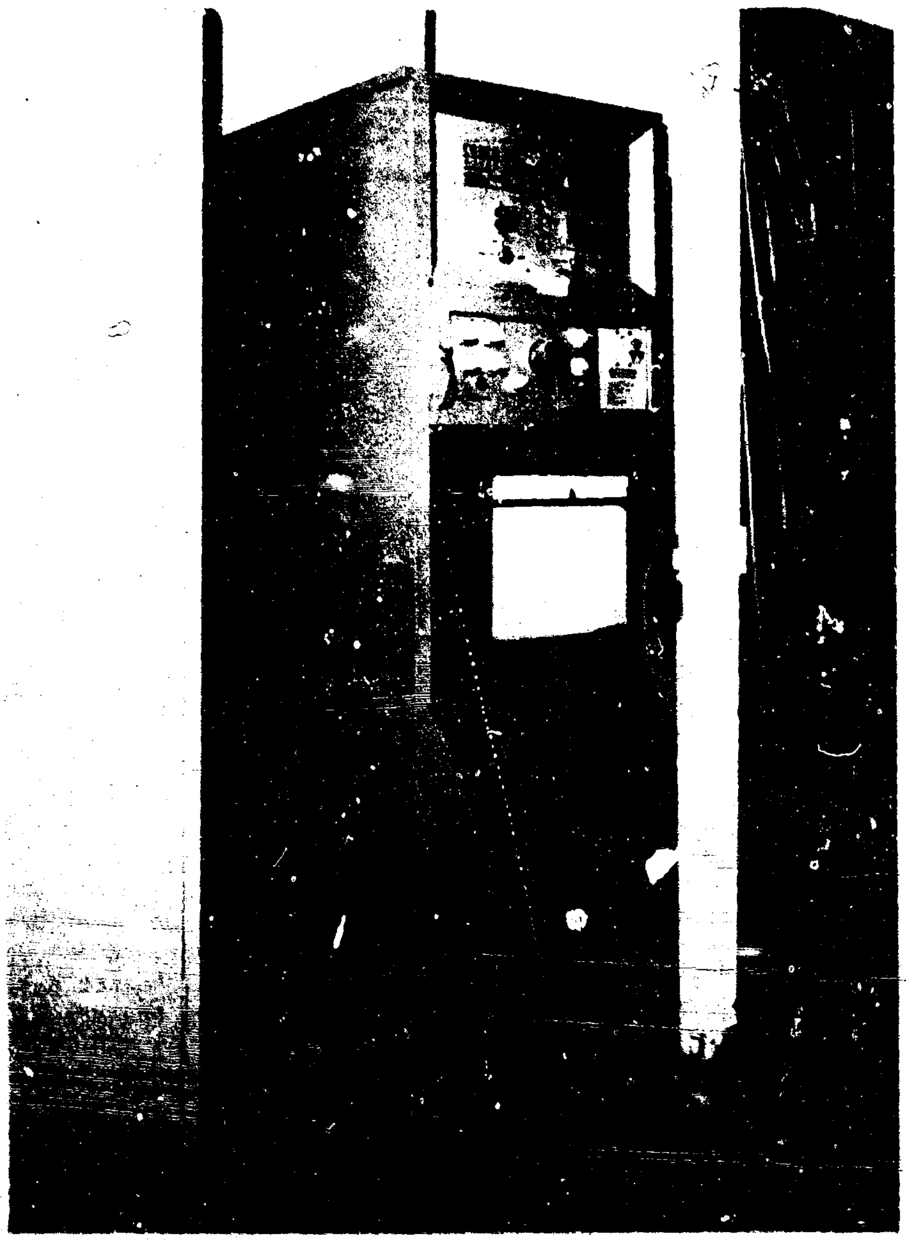


Figure 188. Beta-Ray Hydrogen/Carbon Analyzer FC 12517 EII

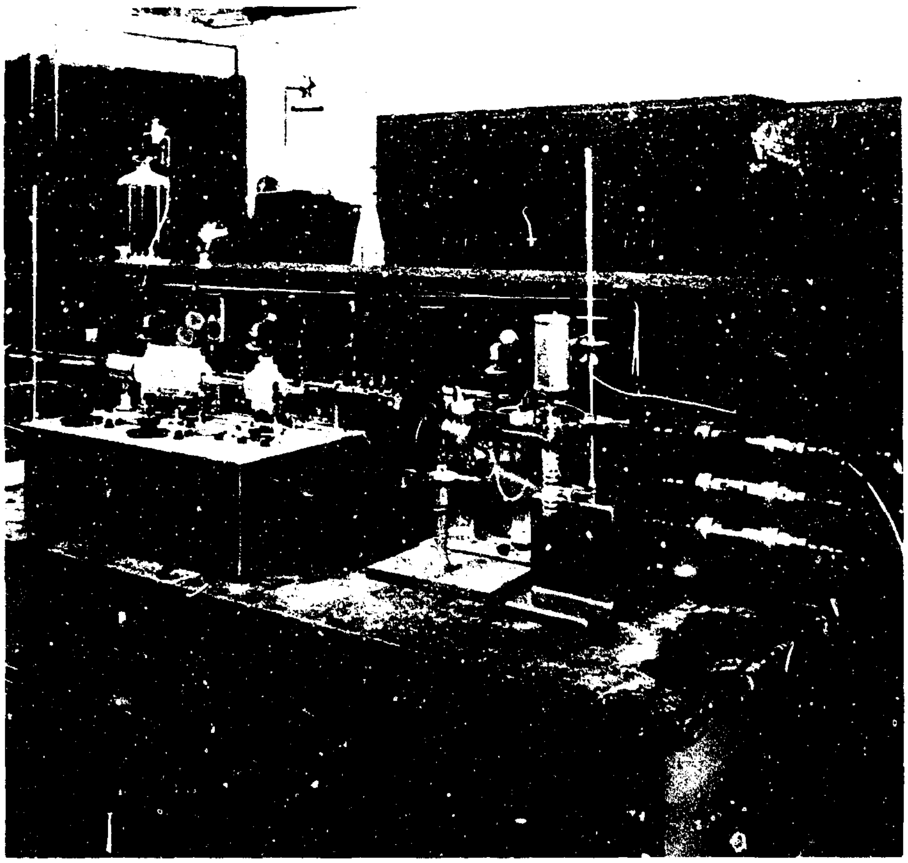


Figure 189. Micro-Combustion Hydrogen/Carbon Apparatus — FC 12528 EII

(11) High Temperature Viscosity

The apparatus that measures high temperature viscosity is shown in figure 190. It consists of a viscometer tube suspended in an enclosed heavy-wall glass tube. Heat transfer oil surrounds the viscometer. The oil is heated by a tape wrapped around the glass tube. The heating medium is circulated by a magnetic stirrer. Pressure is applied within the glass tube with quantities of gaseous nitrogen sufficient to depress the vapor pressure of the sample to a negligible value. The sample within the viscometer tube to the starting position is manipulated by adding gas pressure to one end of the viscometer tube only. Efflux time is obtained by observing the flow of the sample within the calibrated bulb as is normally done for viscosity measurements.

(12) Infrared Spectrophotometer

The infrared spectrophotometer shown in figure 191 is a double beam instrument with extremely high resolving power, capable of qualitative, quantitative, and structural chemical analysis of liquid, solid, and gaseous phase samples.

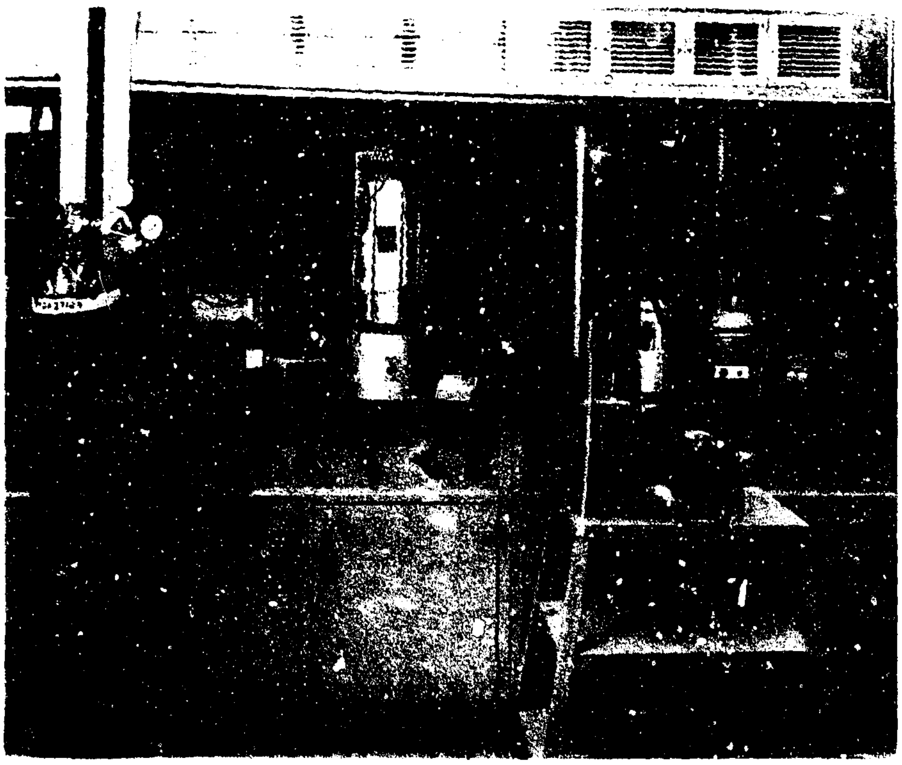


Figure 190. High Temperature Viscosity Apparatus FC 12523
EII

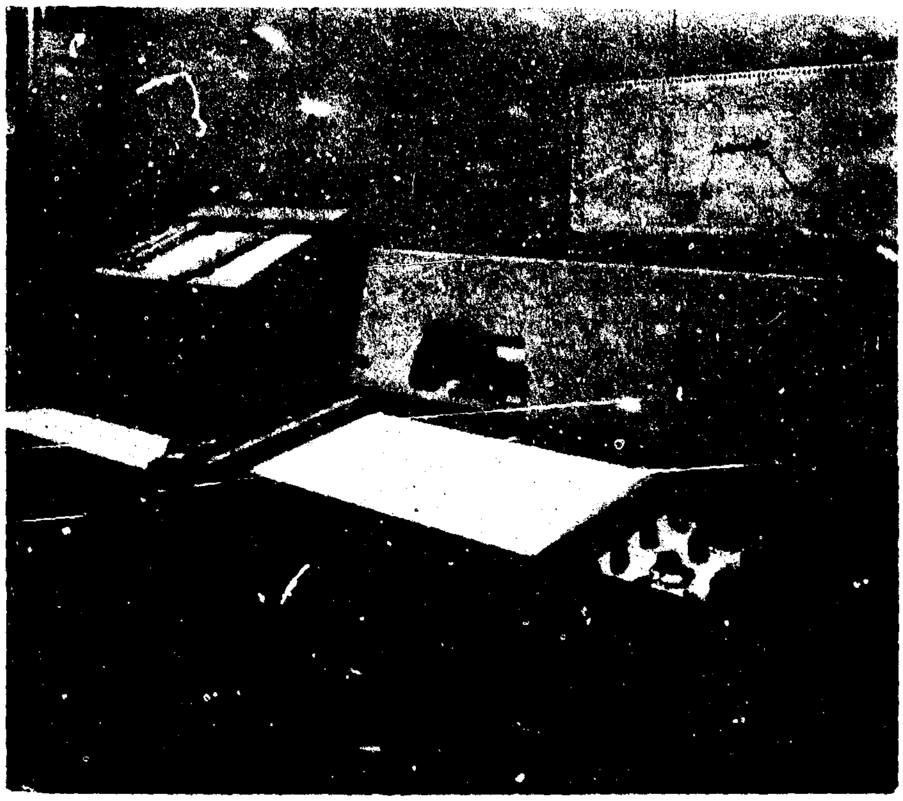


Figure 191. Infrared Spectrophotometer FC 12511
EII

Most materials transmit some portions of the electromagnetic spectrum and absorb others. If the amount absorbed is plotted against the wave number, the resultant is the infrared spectrum of the sample. Each component has its own infrared absorption spectrum. Therefore a mixture of two or more components will yield an absorption spectrum containing the characteristics of all the components. The transmittance at each wave number is the product of (1) the combined transmittances of the components of the mixture at that wave number, (2) the contribution of each component depending upon its concentration, and (3) its absorption coefficient at that frequency.

The sodium chloride fore-prism/grating optical system incorporated in the monochromator permits scanning a continuous range from 650 to 4000 wave numbers (cm^{-1}). Sample data are presented on a linear strip-chart recorder in terms of percent transmittance, absorbance units, or energy versus wave number.

Infrared analysis is a valuable tool in many areas. Among those employed are organic contaminants in fuels and oils, additive concentrations in fuels, and identification of organic contaminants.

(13) Ultraviolet and Near Infrared Ratio Recording Spectrophotometer

The instrument shown in figure 191 is a double beam photometer ratio recorder model that incorporates a multi-speed recorder with scale expansion. An additional feature is a flame attachment that permits conversion to a flame photometer. In addition to the flame, two other sources are provided: a tungsten lamp for operation in the visible region of the electromagnetic spectrum, and a hydrogen lamp for operation in the ultraviolet region. Detection is accomplished by a lead sulfide cell when the tungsten lamp is in use, and by a photomultiplier when the hydrogen lamp is in use.

The principle of operation is very similar to that of the infrared spectrophotometer, the significant difference being in the region of the electromagnetic spectrum which is presented. The hydrogen lamp permits scanning the region from 185 millimicrons to 700 millimicrons, while the tungsten lamp is utilized for the region from 700 millimicrons to 3500 millimicrons. When used as a flame photometer, both regions may be employed.

The instrument is used for quantitative determination of contaminants such as liquid organic materials and additive concentration in fuels and oils.

(14) Mass Spectrometer

The mass spectrometer shown in figure 192 is a precision electronic instrument capable of providing quantitative or qualitative analyses of mixtures of gases and direct individual measurement of any constituent within the mass range of 1 to 100.

All substances are unique with respect to the arrangement of atoms within their molecules. Unique, too, is the manner in which these molecules break up when bombarded by an intense electron beam.

Figure 192. Mass Spectrometer FC 12521
EII

In actual operation a sample is introduced into the system which is at low pressure (approximately 1 x 10^{-7} mm Hg). The sample molecules are in turn bombarded by an electron flow, and the resulting charged particles are then injected into crossed magnetic and electrostatic fields. It is here that the particles are separated into groups according to their mass numbers. The relative intensities of the groups are measured by amplifying and recording their respective output signals.

The applications of a mass spectrometer include (1) a line monitor as a component in process control system, (2) an analytical instrument for engine combustion and efficiency studies, and (3) a leak detector for control of system-atmospheres.

4. Lubricants

a. Introduction

The JTF17 engine will operate on currently available gas turbine engine lubricants that meet PWA 521 (Type II) Specification. Type II lubricants are currently being used by the airlines. Therefore, their use in the JTF17 engine will not increase lubricant cost or lubricant storage problems to the airlines. This paragraph describes the Phase III lubricant test program to substantiate the use of currently available PWA 521 Type II lubricants in the JTF17 engine by complete laboratory evaluation of candidate Type II lubricants prior to rig and engine testing.

b. Lubricant Program

The program to demonstrate the suitability of PWA 521 (Type II) lubricants will include: (1) laboratory testing, (2) component rig testing in both bearing compartment and complete engine lubrication system rigs, and (3) final evaluation in JTF17 engine testing.

After the candidate lubricants have been screened in the laboratory, the most promising candidates will first be rig-tested in full-scale bearing compartment rigs and then tested in a full-scale oil system and gearbox integrated test rig. This testing will determine overall performance and life durability of the lubricants. These rig tests will indicate the effects of long-time operation and resultant dirt ingestion and sludge buildup on cooling effectiveness, oil distribution, and bearing and seal operation.

A complete description of these rigs and the test programs are presented in Section II D-1 of this report. Only the laboratory testing is presented herein.

The major laboratory program will be a continuing investigation of currently available Type II lubricants. Pratt & Whitney Aircraft, FRDC and East Hartford, will conduct the industry coordination and laboratory screening program required to obtain the most desirable lubricant for the JTF17 engine. Additional laboratory testing will be conducted by various independent laboratories, and by the East Hartford facility. This testing, such as Erdco bearing rig tests, will evaluate the thermal and oxidation-corrosion stability characteristics of the candidate lubricants. Paragraph c below explains in detail the description and function of FRDC laboratory equipment and procedures that P&WA plans to utilize during the Phase III Lubricant Program.

c. Description and Function of FRDC Laboratory Equipment and Procedures

The majority of the laboratory tests to screen the currently available oils will be conducted at the Florida Research and Development Center. The FRDC laboratory facilities are equipped to permit

adjusting the severity level of lubricant evaluations to assure proper performance under engine flight conditions. Numerous physical and chemical property evaluations are performed on the lubricants, in addition to the regular laboratory tests (such as pour point, viscosity, specific gravity, flash point, refractive index, and micro combustion). Figures 193, 194, and 195 show some of the apparatus that will be used. The lubricant load-carrying tests (Ryder gear rig), bulk modulus apparatus, infrared spectrophotometer, ultraviolet and near-infrared ratio recording spectrophotometer, and high-temperature viscosity apparatus, which are discussed in Section IID-3 of this report, are also used in the lubricant evaluations. Additional test apparatus and procedures are presented in the following paragraphs.

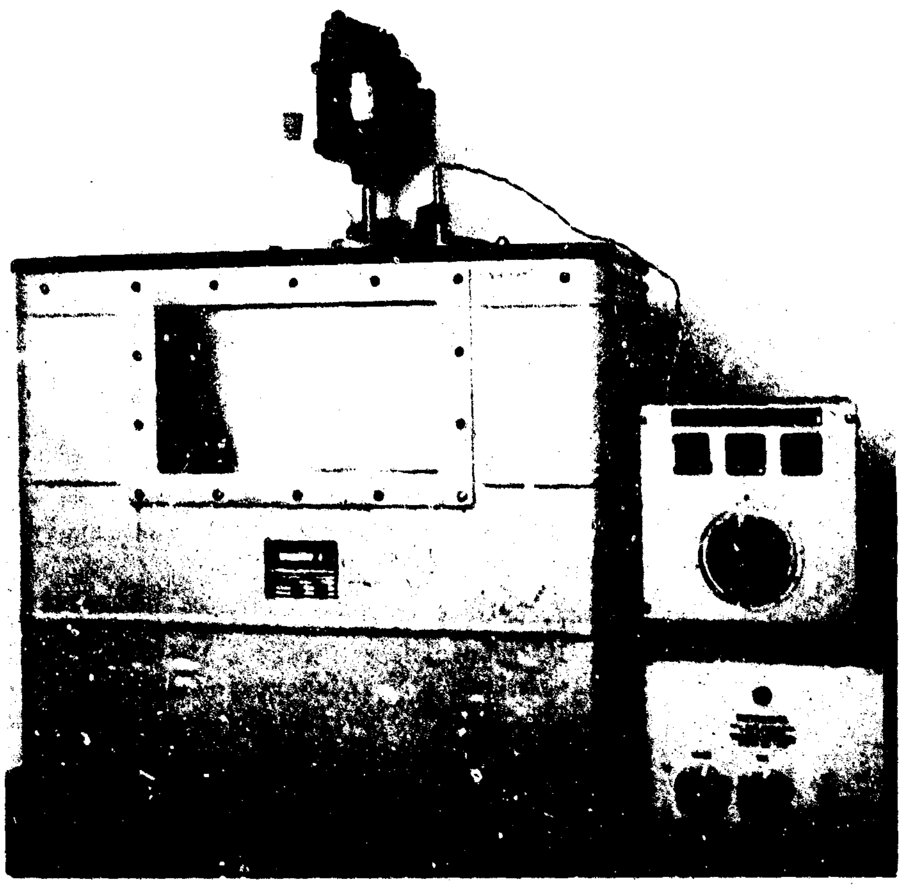


Figure 193. Low Temperature Viscosity Bath **FC 10535 EII**

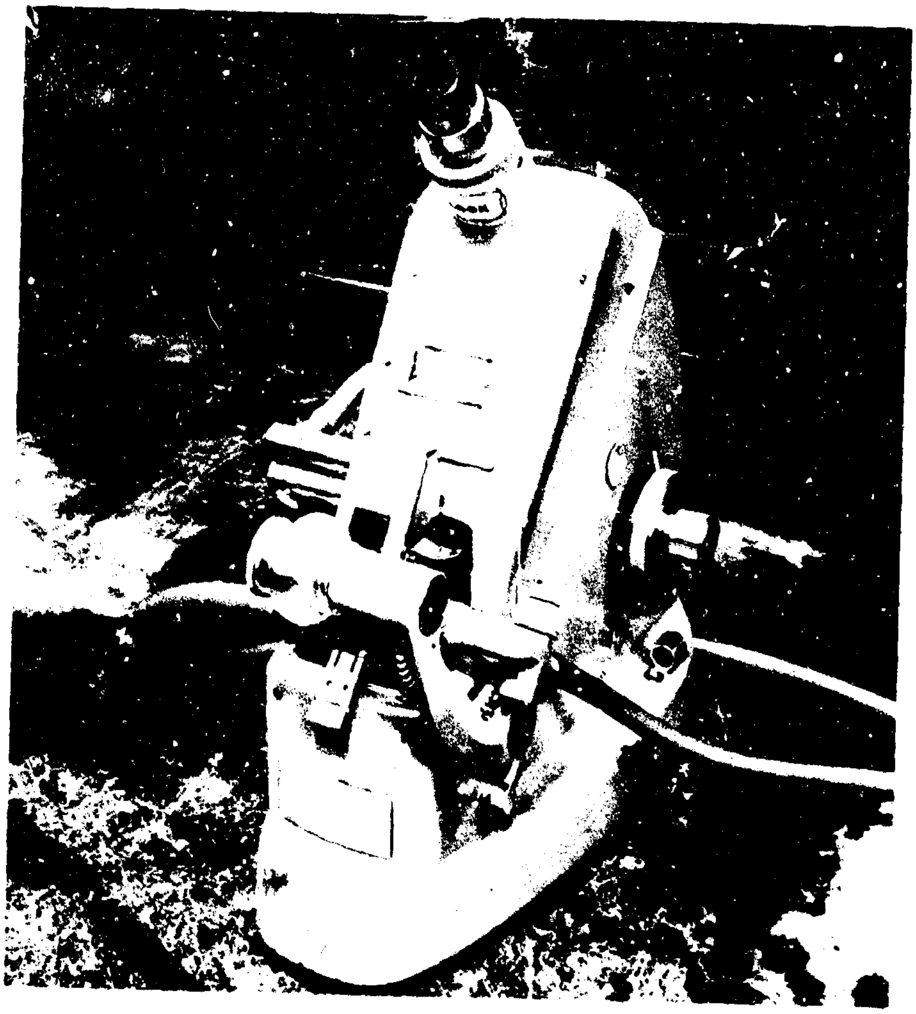


Figure 194. Refractometer

FC 12534
EII

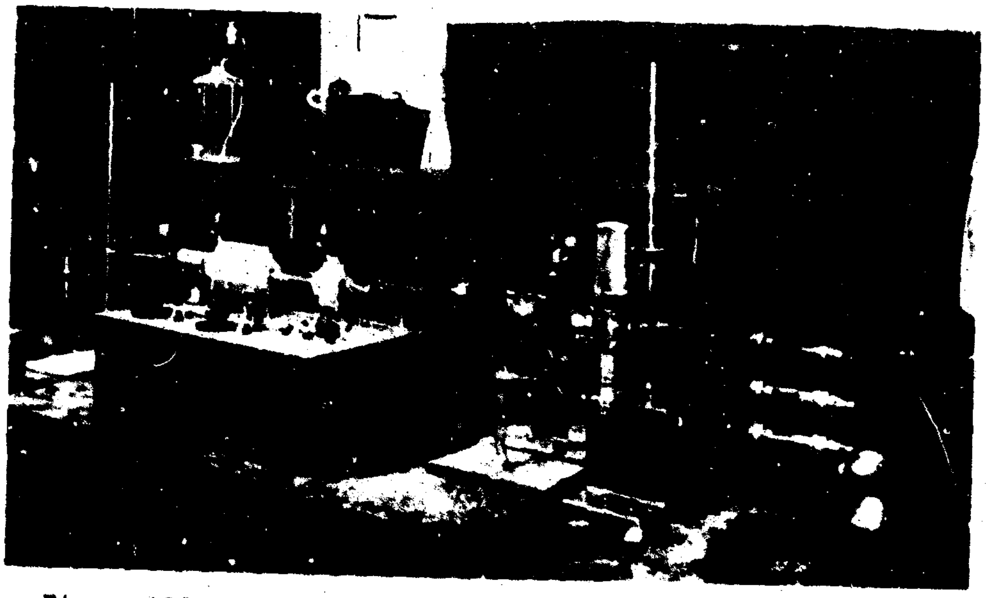


Figure 195. Micro-Combustion Apparatus

FC 12524
EII

(1) Vapor Pressure Measurements

Vapor pressure data of all liquids used by turbine engines are essential, because different liquids are exposed to wide temperature and pressure ranges. Therefore, these liquids require different hardware approaches to maintain low oil consumption and prevent oil pump inlet cavitation during high altitude operation. The vapor pressure of JTF17 fuels and lubricants will be accurately determined by using the following methods: (1) the Isoteniscope vapor pressure method, which is capable of pressure measurements from 0.001 to 15.0 psig; and (2) the bomb vapor pressure method, which is capable of vapor pressure measurements from 0.1 psia to the critical pressures of the test liquids. The facilities used to conduct these tests are shown in figures 196 and 197.

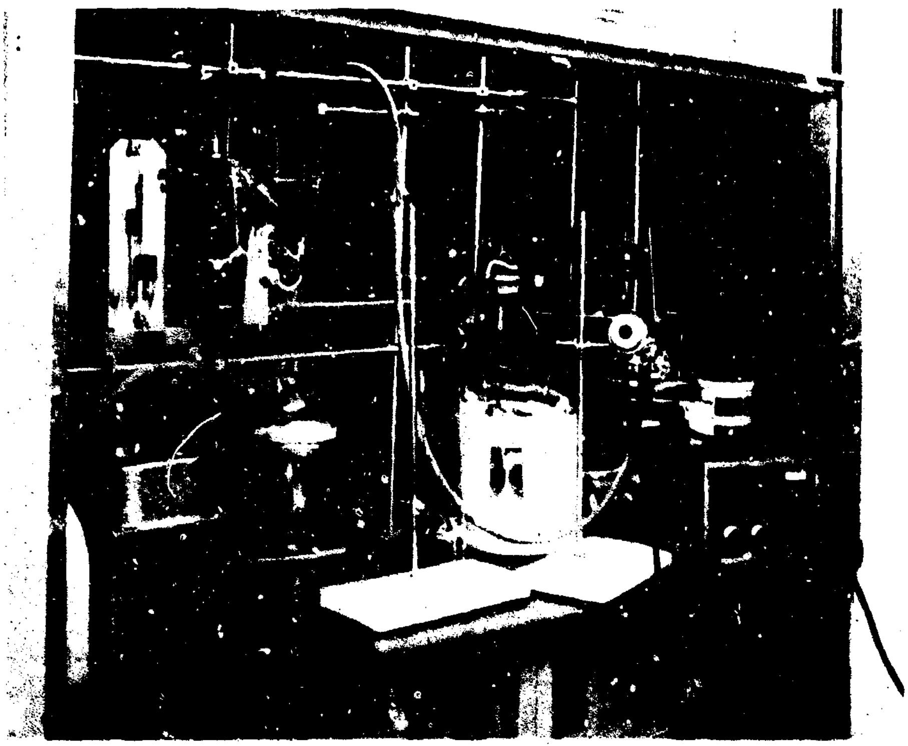


Figure 196. Isoteniscope Vapor Pressure Equipment FC 12500
EII

(2) Corrosion Oxidation Stability of Lubricating Oils

The oxidation resistance of jet engine high temperature lubricating oils, and their corrosive effect on the metal alloys at elevated temperatures, will be evaluated using the apparatus shown in figure 198. Weighed and polished metal panels are suspended in a known quantity of the oil, and sustained at a prescribed temperature for extended periods of time, while clean dry air is passed through the oil. The panels are then examined for evidence of weight change and visible reaction. The oil is also examined for the presence of acidic compounds, gum, or insoluble matter, and to detect any viscosity or neutralization number change.

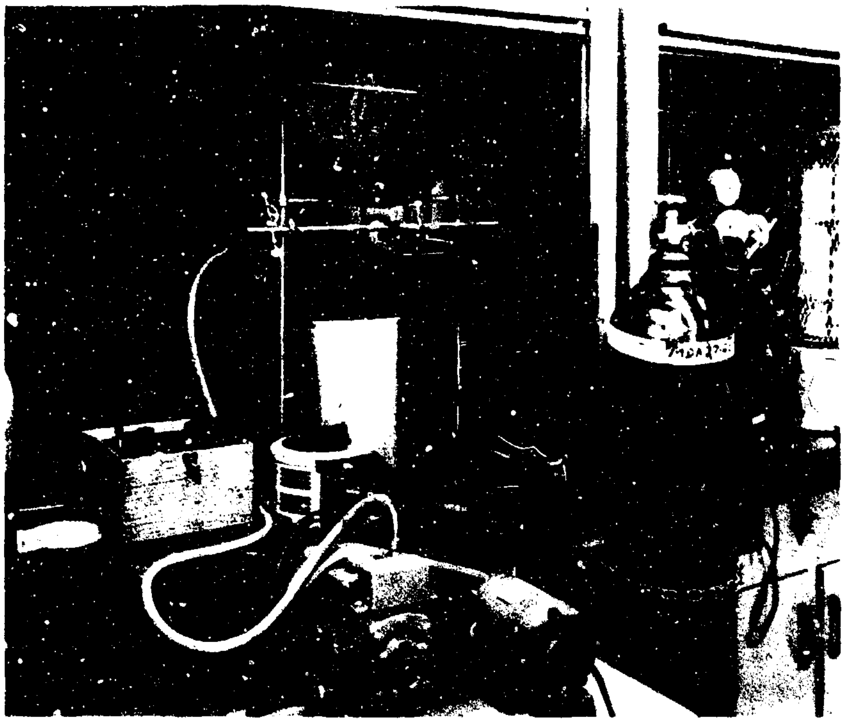


Figure 197. Bomb Vapor Pressure Apparatus FC 12522 EII

Figure 198. Lubricating Oil Corrosion Oxidation Stability Apparatus FC 12530 EII

(3) Lubricating Oil Evaporation Loss Test

The apparatus shown in figure 199 will be used to obtain the data required to predict evaporated oil loss from an engine in flight. The test equipment is adaptable to simulate sea level pressure or the environmental pressure encountered by an engine at high altitude.

Figure 199. Lubricating Oil Evaporation Loss Apparatus **FC 15032 EII**

The oil is tested at simulated altitudes by evacuating the test chamber to the pressures encountered at various altitudes. The test cell, containing a weighed sample, is placed in a forced draft oven, capable of maintaining the specified temperature and pressure, for a period of 6.5 hours. Clean dry air is passed over the test oil at a controlled rate during the test. The percentage of weight lost is then determined.

(4) Specific Heat

Knowledge of the specific heats of all liquids involved in engine operation is of utmost importance when designing heat transfer equipment such as fuel-oil coolers. The apparatus shown in figure 200 is used for the determination of the specific heat of fuels and lubricants over a 100-500°F range. The lubricant to be evaluated is heated electrically with a known amount of energy, and the increase in temperature produced is determined by resistance thermometry. The semiadiabatic conditions are controlled by a thermostatically controlled oil bath. The specific heat is computed from time, energy, and temperature observations during and after heating. Systematic errors are reduced to a practical minimum by calibration of the apparatus over the temperature range with a liquid of known specific heat.

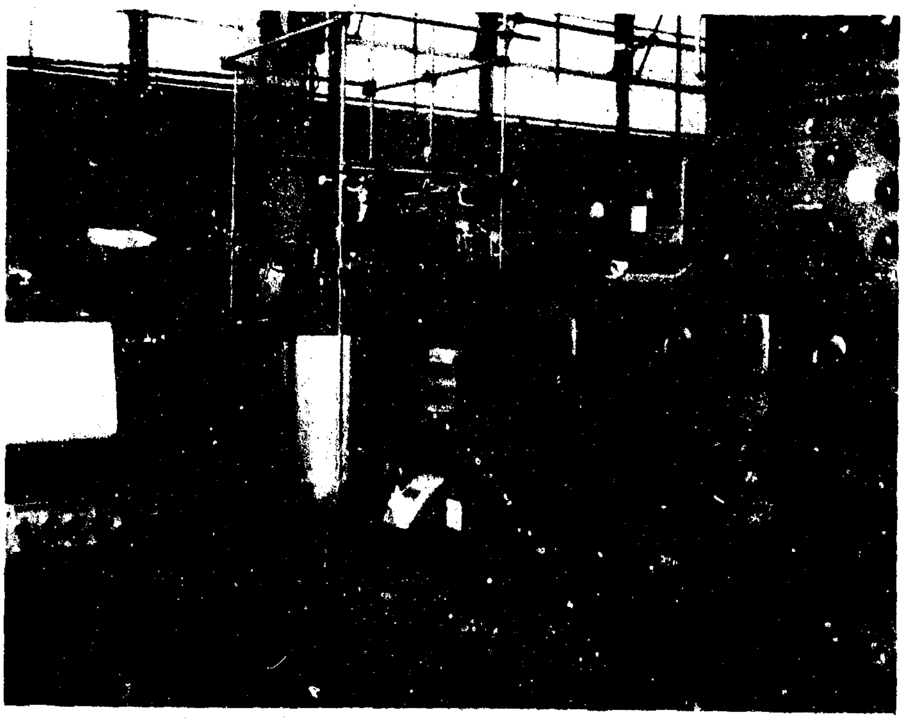


Figure 200. Specific Heat Test Equipment FC 10536 EII

(5) Self-Ignition Temperatures

Temperatures that will ignite the test fluids spontaneously at atmospheric pressure will be determined using a glass flask, heated either by a mantle-type heater or an oven. Temperature readouts at the top and bottom of the flask are made with thermocouples.

The flask temperature is adjusted until a small amount of sample (injected into the flask) is ignited spontaneously within 10 seconds after injection. For reduced or elevated pressures, a stainless steel flask with appropriate valving is heated in the same manner as the glass flask. The steel flask is equipped with a dynamic pressure transducer (to determine pressure surges) and a photocell (to detect light flashes) which will register the ignition indications on an oscillograph.

(6) Gas-Liquid Chromatographs

With the temperature-programmed gas-liquid chromatographs shown in figures 201, 202, and 203, the vaporized liquids are separated and the separated components are quantitatively determined. A small quantity (1-1000 microliters) of the material to be analyzed is injected into a heated column packed with the appropriate absorption material for the test. The sample is instantly vaporized in the column and carried through the column as a vapor dissolved in a flowing stream of carrier gas. By means of absorption and/or adsorption, the column-packing interacts with the various components of the sample vapors, grouping the individual compounds into bands of vapor that elute as separate bands from the column after characteristic times of retention. In some applications, the vapors are analyzed directly in the vapor state as they elute from the chromatograph. In other applications, the components may be condensed automatically in separate containers for study in the liquid or solid state. Several electronic devices are available for the detection, measurement, and further analysis of the separated components. These devices include:

1. Thermal conductivity cells
2. Gas density balance
3. Flame ionization detectors
4. Flame photometric detector
5. Electron capture detector
6. Infrared spectrophotometer
7. Mass spectrometer.

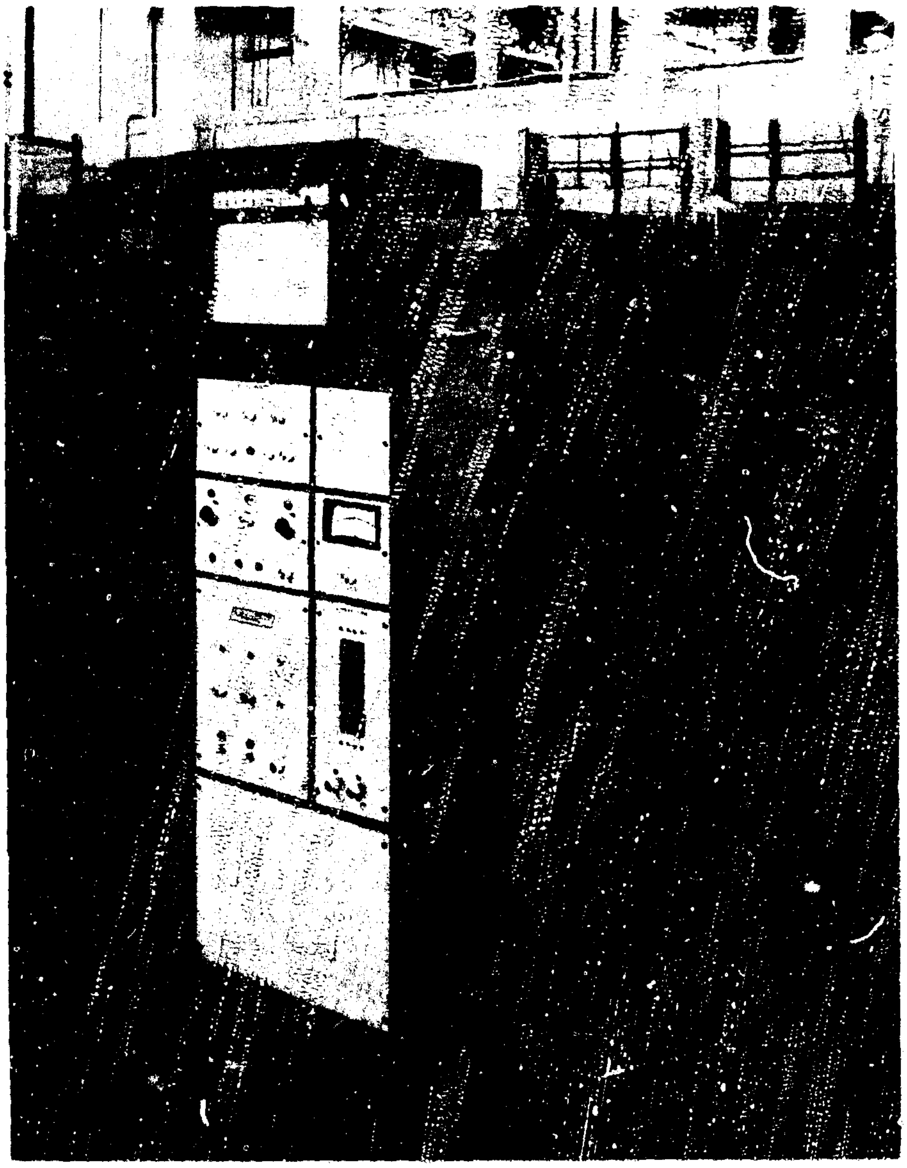


Figure 201. Temperature Programed Research Gas-Liquid Chromatograph FC 12525 EII

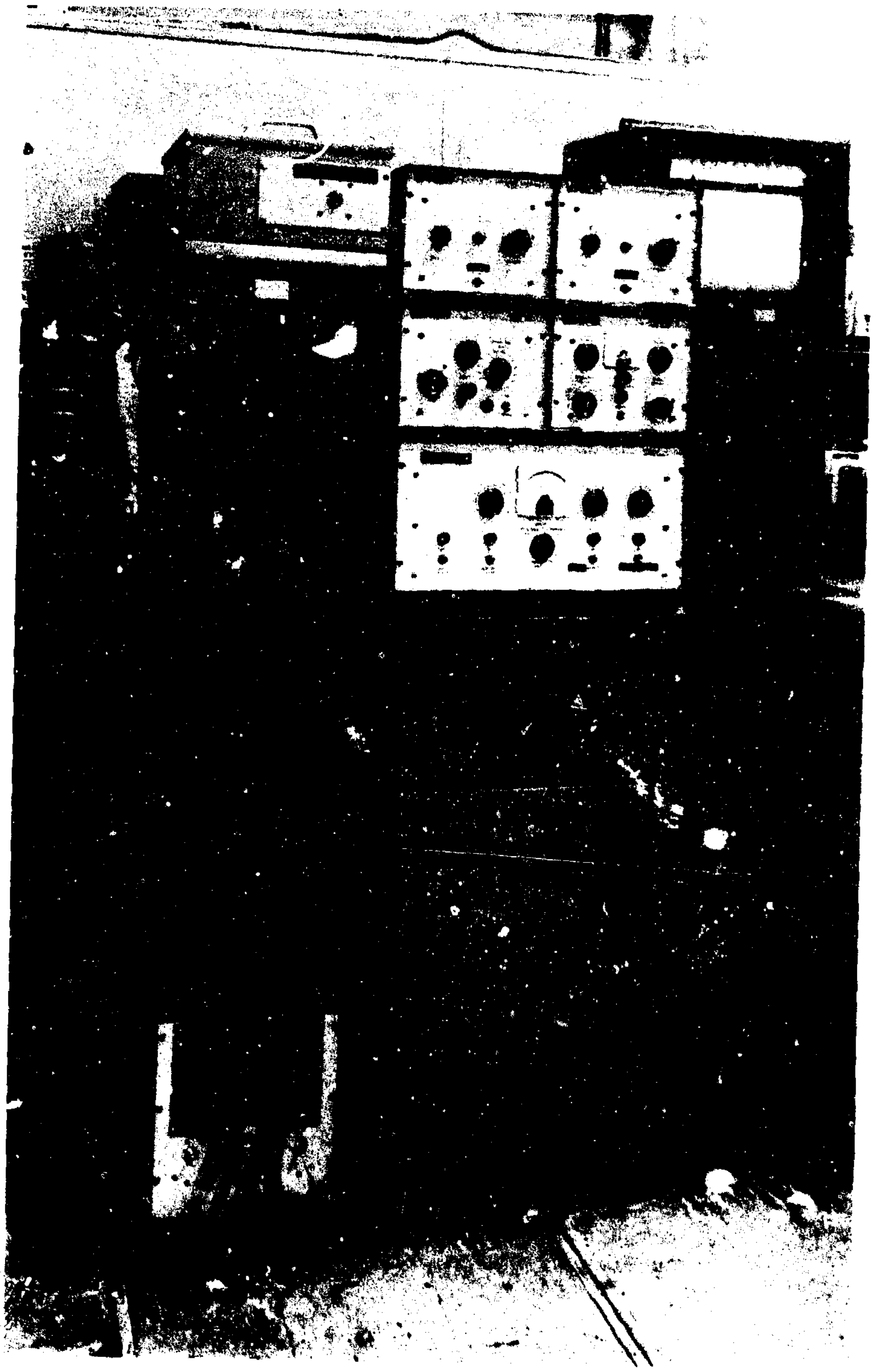


Figure 202. Temperature Programed Gas-Liquid Chromatograph

FC 12505
EII

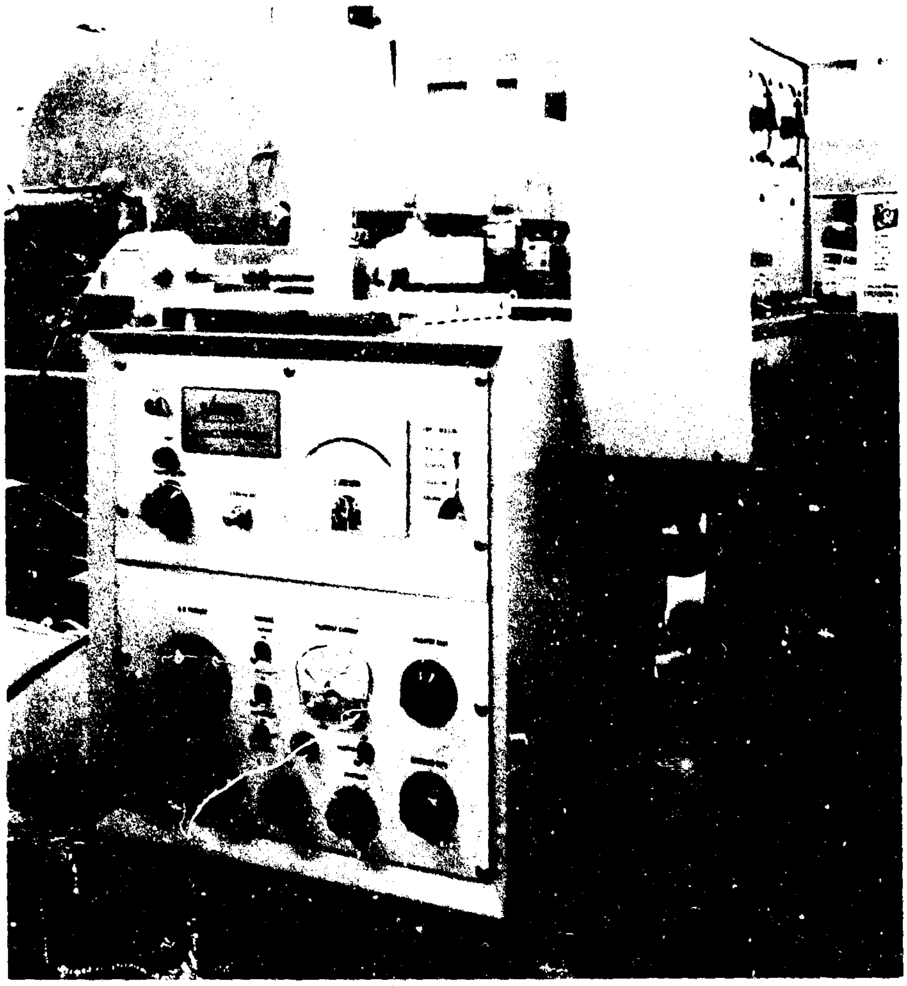


Figure 203. Temperature Programed Automatic Preparatory Chromatograph FC 12535 EII

Gas-liquid chromatography includes: (1) the complete analysis of hydro-carbon fuels and lubricants for quality control, (2) measurement of additive concentrations in fuels and lubricants, and (3) the detection and measurement of contamination in used engine oils. Boiling ranges and average molecular weights of fue.. may readily be determined. The identification of unknown engine deposits is facilitated by gas-liquid chromatography. Detection of dissolved gases in jet engine fuel and oil vapors is possible, facilitating an understanding of vapor pressure and other physical properties of fuels and lubricants.

(7) Atomic Absorption Spectrophotometer

Atomic absorption analyses of new and used lubricants play an important part in the overall role of contamination component-wear rate and contamination detection and control. In the atomic absorption spectrophotometer (figure 204) a sample of the oil is vaporized, usually by a flame. Light, emitted by a lamp whose cathode is made of the metal which is suspected of contaminating the oil, is passed

through the sample vapors. The lamp emits energy only at certain discrete wave lengths which are a function of the cathode material. The metal atoms in the sample can absorb energy at only those wave lengths. The percentage of light absorbed in the oil is, therefore, a direct measure of the concentration of the metal in it.

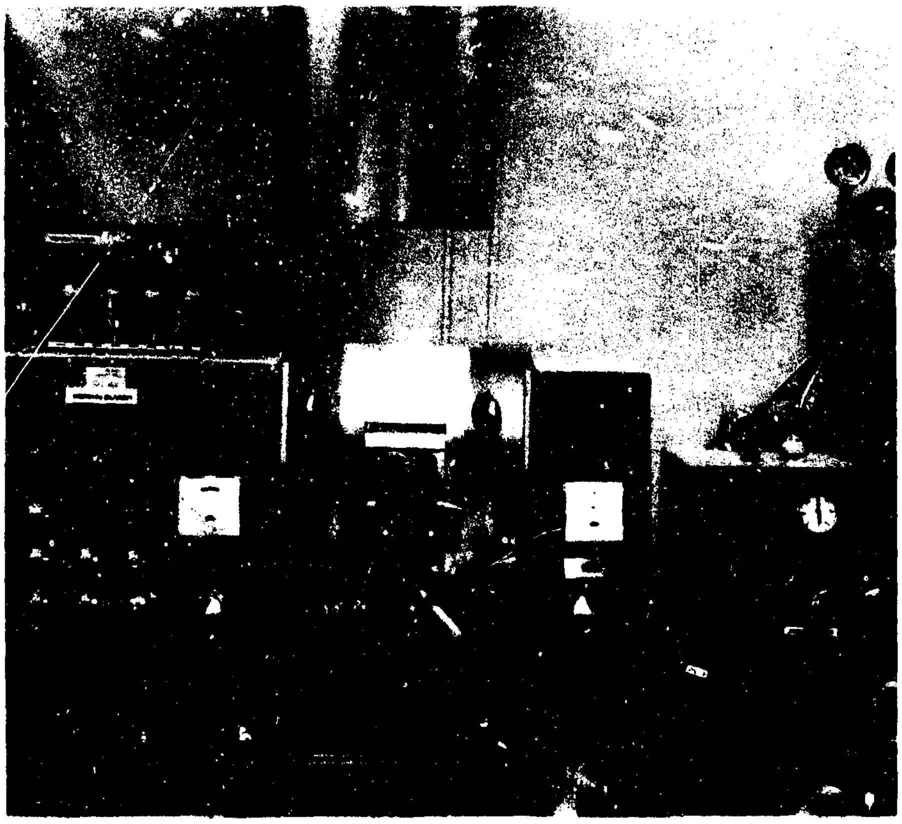


Figure 204. Atomic Absorption Spectrophotometer FC 12510 EII

Atomic absorption can be used as: (1) a precise method for obtaining engine-wear information by measuring metal concentrations in lubricating oils, (2) a simple way of determining metal-additive concentrations in fuels, and (3) a method of determining low-level metal concentrations in metallurgical alloys.

(8) Pitting Fatigue

Pitting failure occurs in gears when particles of surface material separate from the surface as a result of repeated stressing. The pitting phenomenon generally occurs in the vicinity of the pitch line on the gear tooth. If allowed to progress, pitting will weaken the tooth sufficiently to cause breakage. The test apparatus for determining the effect of lubricants on the pitting fatigue life of aircraft quality gears requires standardized equipment, essentially the same Ryder gear rig used for determining the load-carrying ability of lubricants and jet fuels. The pitting fatigue test is an endurance-type test conducted in two stages. Initially, tooth load is

increased progressively to determine that tooth scuff is not excessive. An endurance test is then made at constant operating conditions. Scuifing and scoring of the test gears is minimized by the delivery of a high rate of oil flow to the test gears. Pitting fatigue failure occurs when the pits become large enough to be readily seen by the unaided eye on at least three nonadjacent gear teeth.

E. FLIGHT INSTRUMENTATION

1. Introduction

The JTF17 engine will be equipped with a well-developed flight instrumentation system capable of providing accurate and reliable indications of pertinent engine parameters for airframe readout, ground checkout, and use in the Airborne Integrated Data System. The accuracy, response rate, and signal level characteristics for this instrumentation will be coordinated with the airframe manufacturer and the using airlines during Phase II-C and Phase III, to assure compatibility with the airframe systems and with the engine functions requiring monitoring. Currently, the JTF17 engine design provides the following instrumentation and the following provisions for airframe/airline instrumentation.

a. P&WA Instrumentation

Parameter	Indication	Component
Turbine Exhaust Pressure, P_{t7}	0 - 50 psi	Four probes and averaging manifold
Turbine Exhaust Gas Temperature, T_{t7}	600 - 2000°F	Nine probes wired for average and individual circuits with separate electrical harnesses
Duct Heater Exhaust Nozzle Position (ENPI)	3 - 12 square feet (0-7 inch stroke)	Linear variable reluctance transducer
Reverser/Suppressor Position	Cruise	Electrical switch
Aerodynamic Brake Position (Inlet Guide Vanes)	Cruise (start)	Electrical switch
Secondary Air Valve Position (B eing only)	Closed	Electrical switch

Low Rotor Speed, N_1	0 - 7500	Inductive pickup

b. Engine Provisions for Airframe/Airline Instrumentation

1. High rotor speed tachometer
2. Lubrication oil temperature
3. Lubrication oil pressure
4. Primary gas generator fuel flowmeter
5. Duct heater fuel flowmeter
6. Pressure drop across oil strainer
7. Pressure drop across fuel filter
8. Vibration pickup mounting brackets (2)
9. Fuel pump inlet pressure
10. Fuel pump inlet temperature
11. Lubrication oil quantity
12. Chip detectors

c. Engine/Airframe/Airline Instrumentation Coordination

It is recommended that the airframe/airline selected instrumentation components listed above shall be developed in conjunction with the engine and the engine/airframe development programs. The selection, development, and engine testing of these units as components and as part of the engine system shall be conducted in cooperation with the airframe contractor and using airlines during Phase III. This coordinated effort will provide the instrumentation for safe operation of the engine and for AIDS monitoring of the engine condition to assure the most economical operation of the SST in airline service.

P&WA will assist the airframe contractor and the using airlines in the development of these components by engine testing these units in conjunction with the engine development program. The flight instrumentation system provides connect points for the airframe as indicated on the Installation Drawing. (See Report D, Section I.)

2. State-of-the-Art

The JTF17 flight instrumentation components will be of the same basic design and employ the same operating principles as similar devices used successfully on other P&WA engines, including the TF30 and J58.

This section of the proposal describes the types of sensors, the current state-of-the-art relative to this type of instrumentation, and a description of the Phase III development program planned to assure that the JTF17 flight instrumentation will provide the required accuracy, reliability, and durability. The development test plan is described in paragraph 12, following.

a. Turbine Exhaust Pressure

The turbine exhaust pressure will be obtained by employing four pressure probes that are manifolded in the gas generator cavity to provide an average pressure at the external connector on the engine. The probe is a gas-averaging unit with total pressure sampling at eight locations across the radius of the engine.

Similar probes have been used successfully on the Phase II-C JTF17 engine for the individual location pressure measurement. The development program will be directed toward determining the durability of the probe.

b. Turbine Exhaust Gas Temperature

The turbine exhaust gas temperature measurement will be obtained by employing immersion thermocouples.

The JTF17 exhaust gas temperature probe employs the design refinements developed in the J58 high Mach number program and in the Phase II-C program. Special efforts have been made to obtain designs that eliminate the problems experienced by airline service. The features incorporated into the design to meet these goals are:

1. The installation and removal of the probe through the turbine exhaust nozzle: eliminates the necessity of removing any engine part or engine cowling to replace a defective probe
2. Simple-beam-support probe configuration: provides reduction in gas bending stresses and improves vibratory damping
3. Machined-heavy-duty harness eyelets: provides improved durability in eyelets and eyelet/leadwire joint
4. Improved bracket attachments: provides tight fit between bracket and harness during thermals and during normal installation to avoid chaffing.

The JTF17 exhaust gas thermocouple transmission harness is a flexible two-piece assembly covered with a braided-nickel wire shielding. A junction box joins the two sections of the harness at the rear of the engine exhaust case, facilitating installation and removal of the harness.

A development program will be conducted on the probes and harnesses to improve the durability and reliability in the following areas:

1. New fabrication methods that will eliminate internal wire failures caused by vibration and handling
2. Quick-disconnects in probe design to allow rapid and easy removal on installed engines
3. New methods of measuring gas temperature applicable to turbine inlet temperature measurement.

c. Exhaust Nozzle Area Indicator

The exhaust nozzle area position indicator will use a linear variable reluctance transducer connected to the duct exhaust nozzle mechanism to produce an output signal proportional to the duct heater exhaust nozzle area. This electromagnetic transducer has windings encased in a stainless steel housing, and a movable, magnetic stainless steel rod, which does not require sliding contacts or moving leads. A fuel-cooled unit of this type has been successfully employed on the Mach 3+ J58 engines. This experience will be utilized to develop the transducer for accuracy, reliability, and durability.

d. Position Indicators

The inlet guide vane position, reverser-suppressor position, and secondary air valve position (Boeing only) will be obtained by the use of mechanically actuated switches designed for precision operation at elevated temperatures. The design will utilize a snap-action contact that will provide increased reliability by reducing the effect of contact arcing. Switches of this type have been successfully used on the J58 engine at temperatures that are several hundred degrees higher than will be experienced on the JTF17. This high-temperature experience will be employed to develop the JTF17 switch to reliability and durability levels consistent with the requirements of commercial service.

These switches will indicate component positions as follows:

1. Inlet guide vane - cruise (start)
2. Reverser-suppressor - cruise
3. Secondary air valves - closed (Boeing only)

e. Low Rotor Speed (N_1)

Low rotor (fan) speed will be obtained by the use of an inductive pickup that is located approximately 0.001 inch above the maximum tip thickness of the 2nd-stage fan blades. This pickup employs the concept known as "stray magnetic field effect"; therefore, no "return" magnetic circuits or paths are necessary. The dynamic discontinuity generated by the fan blades in the field of the pickup pole piece produces an electrical output. This output voltage and wave shape require amplification and shaping by an amplifier located within 200 feet of the pickup. A differential operational amplifier and an analog or digital readout for this rotor speed are recommended.

The inductive pickup output voltage and wave shape are dependent upon the following characteristics of the interrupting material:

1. Probe-passing velocity of the blade
2. Mass or size of the blade
3. Magnetic properties of the blade
4. Distance from the pickup.

The 2nd-stage blades of the JTF17 design will produce the dynamic discontinuity required by the inductive speed transducer. Laboratory tests and J58 development experience have indicated that a specially designed low inductive pickup will produce a useful and reliable speed signal when positioned above a rotating rotor. A similar low inductive pickup has been utilized on the J58 engine as a means of detecting blade flutter. During a laboratory test conducted with the J58 pickup, the output signals were routed through 200 feet of standard cable to a Differential Operational Amplifier, which produced a shaped signal of 0 to 20V between speeds of 0 to 30,000 rpm.

3. Test Program Objectives

The test program objectives for the flight instrumentation components are as follows:

a. To develop each component in conjunction with the engine/airframe development to meet the engine and airframe operational requirements as defined in purchase specifications and component calibration schedules

b. To provide component designs that provide accuracy, reliability, durability, and ease of maintenance.

Extensive testing, including altitude, hot and cold environments, vibration, acceleration, impact, explosion proof, electrical interference, sand and dust contamination, humidity, and fungus--as applicable to each unit--will be accomplished. Primary emphasis will be given to the vibration and environmental tests to develop component accuracy, reliability, and durability. The remaining tests will be performed as required to ensure component operation under all normal engine conditions and to insure functional margin for abnormal engine conditions so that these units will provide AIDS input for troubleshooting.

4. Facilities and Equipment

The facilities and equipment required for the development of these components are available at P&WA and vendor facilities. These test benches are equipped to provide electrical power, mechanical inputs, ambient environments, electrical gages, etc, to test the components. Special instrumentation and automatic data recording equipment are available. A detailed description of the P&WA facilities is included in Volume V, Report B (Facilities Program).

5. Component Test Programs

The instrumentation components are, in most cases, items of proprietory vendor design and will be procured to specific PWA Purchase Specifications. Each specification will define the performance requirements and the required substantiation tests. These requirements and tests will be based on the engine/airframe specification and environmental conditions and from previous experience on the same

or similar components. Representative Purchase Specifications are available for review at FRDC.

Component testing will be conducted at P&WA and the vendor facility to develop each component to meet its requirements of simplicity, accuracy, reliability, and maintainability. These tests will include calibration, environmental, vibration, acceleration, impact, explosion proof, electrical interference generation and susceptibility, sand and dust contamination, humidity, and fungus--as applicable to each unit--and as defined by the applicable military standards.

All vendor test programs, including compliance with the purchase specification, shall be approved by the cognizant P&WA Project Engineer. After the tests are completed, a report will be submitted by the vendor to P&WA for approval.

As soon as hardware becomes available at P&WA, bench and engine tests will be run to determine any component deficiencies and to evaluate corrective action.

a. Turbine Exhaust Pressure Probe

The turbine exhaust pressure probe will be subjected to engine test to determine durability and maintainability of the unit.

b. Turbine Exhaust Temperature Probe

The turbine exhaust gas thermocouple probes and transmission harness will be subjected to the high temperatures, vibration, acoustical and gas loads of the engine during the engine test program to develop and demonstrate the required accuracy, rapid response, durability, maintainability, and resistance to fuel and moisture absorption. Bench tests of two engine sets of thermocouples and harnesses will be conducted in an oxidizing atmosphere at their respective environmental temperatures to determine the effect of oxidation. The temperature indication and the insulation resistance will be periodically checked to assure integrity of the probe and harness and to provide service life information. The harness oxidation test will be conducted with the probes attached.

c. Exhaust Nozzle Position Indicator

The linear variable reluctance transducer will be subjected to endurance, vibration, and environmental tests to develop the response, repeatibility, accuracy, reliability, and durability of the unit.

d. Position Indicators

The mechanically actuated switches for indication of inlet guide vane, cruise thrust, and secondary air valve positions will be subjected to environmental temperature endurance tests. The units will be actuated and deactuated every 15 minutes with maximum rated inductance in the external circuit. Contact resistance, open switch

insulation resistance, and insulation from ground will be monitored during the endurance. The effectiveness of the radiated RF interference shielding will be established.

e. Low Rotor Speed Indicator

The test program on the inductive pickup will be directed toward improving the capability of the unit to provide reliable and durable service. The limits of external capacitance and impedance will be determined. Endurance tests will be conducted at the extremes of engine environmental temperature and vibration to establish the durability of the electrical insulations. The effects of each electrical, mechanical, and environmental parameters on output voltage will be investigated.

f. Engine and Airframe/Engine Tests

As soon as hardware becomes available and has been bench-tested to show suitability for engine tests, these units will be added to the engine test programs from which component output levels, accuracies, reliability, and durability will be established.

The airframe/engine ground and flight tests conducted during Phase III will be closely monitored to establish the performance of the integrated flight instrumentation system. The procedures for detection of defective units, installation and removal of units, and ground maintenance requirements will be established.

g. Substantiation Tests

Bench tests will be conducted at simulated mission cycle conditions prior to FTS, and a bench substantiation test is planned prior to the engine Certification Test for the electrical switch, exhaust nozzle position indicator, and inductive pickup.

The FTS and Certification Test for each component will be conducted in conjunction with the engine tests.

6. Usage Schedule

The planned number of each component and the test hours required through Phase III are shown below:

a. Total Test Hours - 50800

b. Number of Units

Component	Units Per Engine	Quantity
Turbine exhaust gas temperature probe, T_{t7}	9	405
Electrical Harness	4	100
Low rotor speed	1	45

Position Indicators		
Electrical Switches		
LCC	2	90
or		
TBC	6	200
Exhaust nozzle	1	39
Turbine exhaust pressure probe, P_{t7}	4	96

This data is presented in graphic form in figure 205.

7. Acceptance Criteria

The acceptance criteria of the individual components shall be that the units will conform to the purchase specification, the engine specification, and to the component calibration schedule prior to engine test; and that, after engine operation to the mission cycle for the specified time, the wear or distress of the parts is insufficient to preclude further satisfactory operation after normal overhaul.

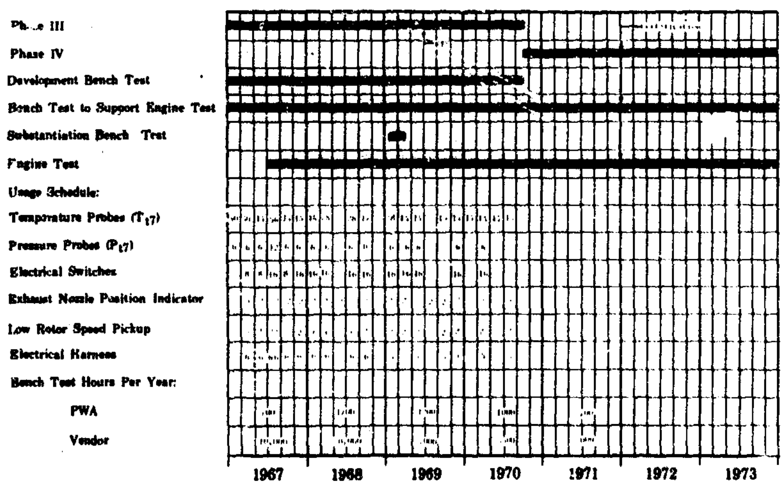


Figure 205. Turbine Exhaust Probes, Position Indicators, and Electrical Harness Development Schedule

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EII

SECTION III
ENGINE DEVELOPMENT PROGRAM

A. INTRODUCTION

The development program for the JTF17 engine is planned to take full advantage of all the experience gained during the development of the successful high Mach number J58 engine and commercial Pratt & Whitney Aircraft turbine engines, such as the JT3D, JT3D, JT3C, and JT4. The JTF17 engine represents a significant but reasonable advancement from previous Pratt & Whitney Aircraft engines in structural concept, aerodynamics, combustion concepts, and lightweight mechanical design features. The gas generator uses a fixed exhaust nozzle, as in other Pratt & Whitney Aircraft commercial turbine engines, and the twin spool concept has been well proved in the more than 6000 JT3, JT3D, JT4, and JT8D engines already in commercial service. The design and performance requirements of the JTF17 engine are defined in the Model Specification, PWA 2698A for the JTF17A-21L and PWA 2710 for the JTF17A-21B.

More than 22,000 hours of development testing accumulated on the J58 engine provide essential experience to conduct a high Mach number engine development program, while the recent development of turbofan engines such as the JT3D, JT8D, and TF30 provides background in turbofan engine development.

The operational J58 flight experience at Mach 3 continuous cruise conditions and Pratt & Whitney Aircraft commercial jet engine experience, accumulated at a substantial rate each day, will be continuously fed into the JTF17 development effort by scheduled Design Board Review. This background of experience will allow a more concentrated effort on proving the reliability and durability of the engine by extensive high Mach number endurance testing and developing the full performance potential of the cycle.

The overall engine test plan serves the following primary purposes and is based on a 30 September 1966 go-ahead for long lead time parts.

1. Early experimental engines will correlate the performance of components developed on rigs described in Section II and will establish their compatibility with the overall engine system.

2. As the engine development progresses, rapid and complete interchange of information and experience between the engine testing and the component test program, described in Section II, will continuously guide the engine design and properly orient the component tests.

3. The development test program is designed to obtain the maximum amount of meaningful information in the shortest possible time. Design changes dictated by test results can thus be translated quickly into hardware, improvements can be verified by further testing, and product maturity can be achieved in minimum time.

4. Careful integration of the engine and component test programs is provided to assure that the JTF17 engine development program will proceed in the most expeditious manner to achieve the required engine performance and maturity. The various major subsystems of the engines, such as the fan, high compressor, controls, burner, and turbine and their interactions are evaluated and developed during the component test program. However, there is no substitute for full-scale engine testing under simulated operating conditions to evaluate and verify the interactions and attain the desired goal of a high performance, dependable engine on schedule and within target cost.

This section describes the planned Phase III engine development program in detail. The succeeding Sections IV, V and VI describe the Flight Test Status Program, the planned support of the Aircraft and Engine 100-Hour Flight Test Program, and an outline of plans for preparation for and conduct of Certification Tests as a basis for application for a model type Certificate from the FAA.

B. PHASE III ENGINE TEST PROGRAM OBJECTIVES

The major objectives for the Phase III JTF17 Engine Development Test Program are to:

1. Develop the JTF17 engine to meet the requirements of Appendix A of the Engine Model Specification. This will entail the manufacture, assembly, and test of at least 12 experimental engines.

2. Demonstrate engine performance as defined in Appendix A of the Engine Model Specification.

3. Demonstrate the durability and reliability required for FTS.

4. Provide assurance that Engine Type Certification can be accomplished in Phase IV.

5. Prepare for successful conduct of FTS test in June 1969.

6. Conduct a vigorous and comprehensive test program in preparation for and in support of the flight test program.

An uninterrupted continuation of the JTF17 development program with timely and adequate funding would lead to achievement of the following additional major objectives during Phase IV:

1. Demonstrate the engine performance as defined in the Engine Model Specification.

2. Demonstrate the reliability and durability required for Engine Type Certification.

3. Complete the Engine Type Certification Test in December 1971.

4. Conduct a vigorous and comprehensive test program in support of the flight certification test program.

5. Complete Airframe Certification 5 May 1974.

A continuing development program will be conducted beyond airframe certification directed at support of the SST. This program will include solution of service problems and growth of the engine. The potential growth of the engine is described in Volume III, Report G.

C. ENVIRONMENTAL TESTS

Environmental engine testing is conducted in sea level ram test stands and the altitude facilities with inlet and secondary air supplied at simulated altitude Mach numbers. Secondary airflow and temperature will be representative of SST flight conditions. It is anticipated that 2000 hours of full-scale engine environmental testing will be completed by FTS and 7250 hours by the time of engine Certification. The need for this high proportion of environmental testing has been well-substantiated in the production-qualification program conducted on the J58 engine. Fundamentally, environmental testing is necessary because unlike a subsonic engine, a supersonic cruise engine and its parts are not subjected to rigorous enough time-stress-temperature relationships using traditional "sea-level" testing.

D. PROGRAM SCHEDULE

The proposed development program for the JTF17 engine draws heavily on the experience gained in the development, production, and flight operation of the J58 engine and other successful Pratt & Whitney Aircraft engines such as the TF33P7 and the JT8D turbofan engines. The anticipated hours of engine testing required to meet the test objectives above are shown in table 1.

Table 1. JTF17 Test Objectives

	FTS	End of Ph III	Engine Certification	End of Ph IV
Total engine time, hr	4,000	8,000	14,500	27,500
Heated inlet time, hr	2,000	4,000	7,250	13,750
Rated turbine inlet temperature time, hr	2,400	4,800	8,200	16,500
Augmented time, hr	2,400	4,800	8,200	16,500
Simulated altitude - Mach number time, hr	1,600	3,200	5,800	11,000
Total number of active engines in program	12	12	15	15

Definitions:

a. Heated Inlet Time is at engine inlet temperature of Mach 1.5 or above.
b. Simulated altitude Mach number time is time at cruise environment.

A major milestone chart for accomplishing the program objectives is shown in figure 1. The planned rate of introduction of experimental engines into the development program is patterned after the development program of the supersonic J58 engine and is not significantly different from other successful Pratt & Whitney Aircraft engine programs in either total number of engines or rate of delivery as shown in figure 2. The three JTF17A-20 engines manufactured and run during Phase II-C will be refurbished to the JTF17A-21 engine parts list during the early stages of Phase III.

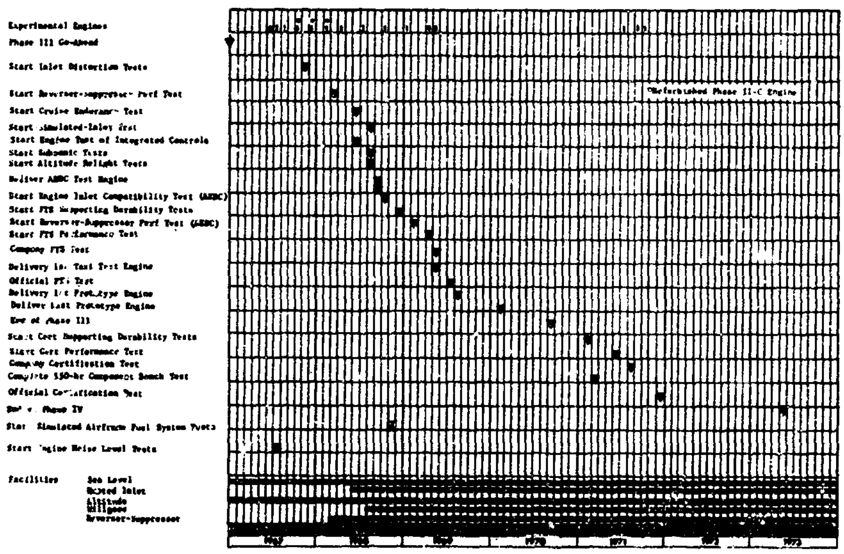

Figure 1. Milestone Chart - Engine Development FD 16656 EIII

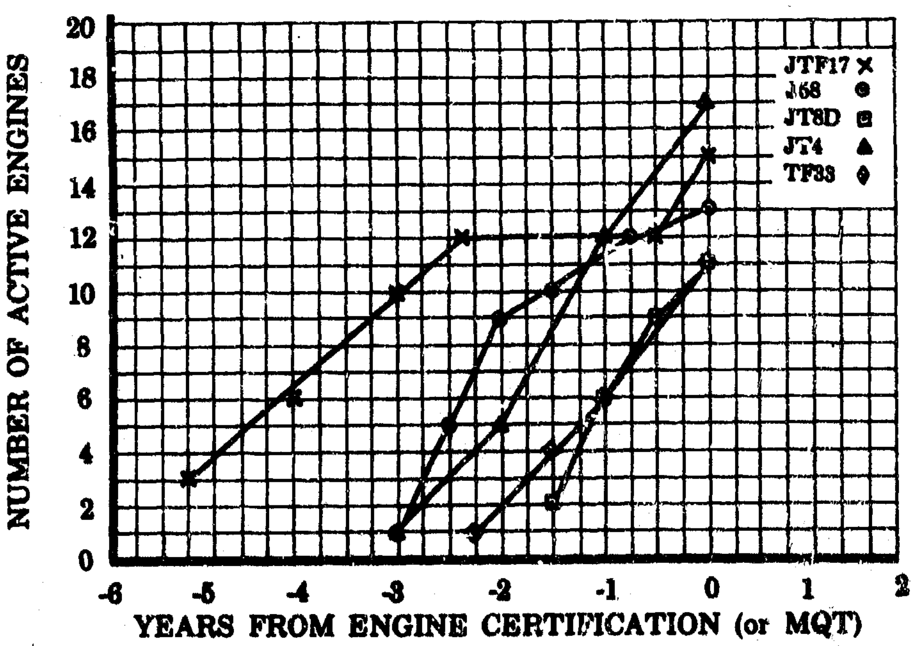

Figure 2. Number of Active Engines FD 16657 EIII

A plot of proposed engine hours vs calendar times for the JTF17A-21 engine is shown in figure 3. This plot includes total time, heated inlet time, simulated altitude - Mach number time, augmented time, and rated turbine inlet temperature time. Included on this plot is the development engine schedule.

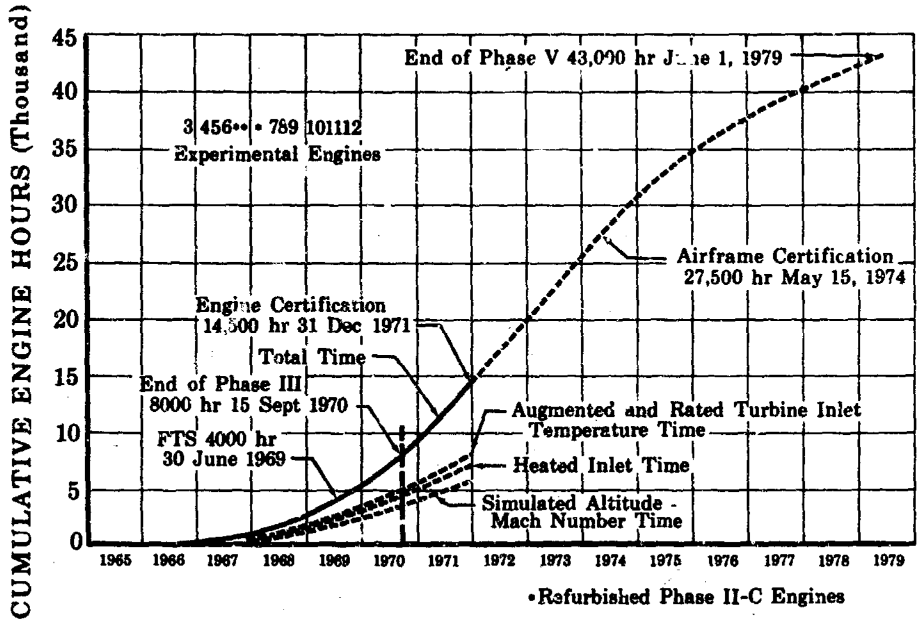

Figure 3. Estimated Cumulative Engine Hours FD 16658 EIII

Table 2 shows a comparison of the proposed cumulative JTF17 engine test hours to the hours accumulated during previous P&WA engine developments, up to the completion of the Certification Test (or MQT in some cases). Also shown are the number of active engines in each test program at Certification (or MQT).

Table 2. Engine Test Comparison

Engine Model	Hours at Certification		Number of
	Total	Heated Inlet	Active Engines
JTF17	14,500	7,250	15
J58*	9,900	3,000	13
J57*	6,300	-	13
TF33*	4,200	-	11
JT8D	5,400	-	11
TF30	13,500	850	17
J75	8,400	-	17

*Qualification Test rather than Certification Test.

The J58 engine is the only engine that has been developed to production qualification status for continuous supersonic cruise operation. The need to conduct a significant portion of the engine testing at supersonic environment conditions was clearly demonstrated in this program. This requirement is peculiar to engines operating continuously at high supersonic speeds, and the J58 engine history is therefore the most logical basis for determining the development testing that will be required for the JTF17 engine. Although the J58 engine development involved comparable problems at high Mach numbers and high turbine inlet temperatures, the J58 engine was qualified after fewer engine test hours than are proposed for the JTF17 engine. That the JTF17 engine will be required to meet more stringent engine life and reliability requirements in airline operation accounts for this approximate 50% increase in test hours compared to the J58 engine. These additional hours will be accumulated by increasing the test time (another full year of testing for the JTF17 engine) as well as the number of engines (two more engines in the JTF17 engine program). To determine if the testing rates were comparable for these two engines, the curves in figure 4 were plotted to show the average hours per test engine in the program up to Certification Test (or MQT) completion. These curves show clearly that the slope (or rate of engine testing) is indeed similar for the actual J58 engine program and the proposed JTF17 engine program. Therefore it is concluded that the proposed engine test program is reasonable and consistent with previous P&WA experience.

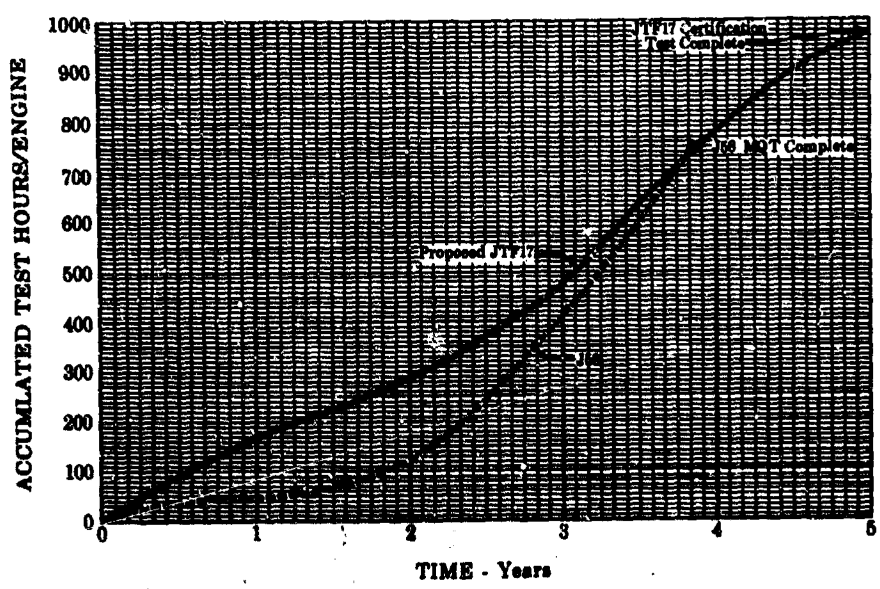

Figure 4. Predicted JTF17 Engine Test Time to Certification FD 17914 XIII

The program to be accomplished by each development engine and the estimated number of test hours for each category is shown in figure 5.

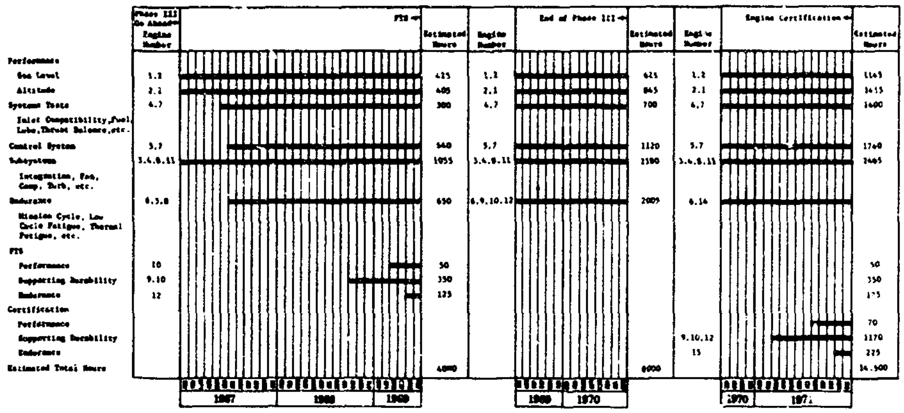

Figure 5. JTF17 Program Schedule

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EIII

It is planned that government facilities will be used for two important phases of the JTF17 engine development program; the engine-inlet compatibility testing and the reverser-suppressor performance validity test. Table 3 is a time table for the anticipated use of these facilities.

Table 3. Facilities Usage Time Table

	Start of Program	Completion of Program
Engine-Inlet Compatibility Test at AEDC	October 1968	March 1969
Reverser-Suppressor Internal Performance Test at AEDC	January 1969	February 1969 (2 months)

E. PHASE II-C STATUS AS OF 1 AUGUST 1966

1. General

The JTF17 demonstrator engine has demonstrated durability and performance levels as would be normally anticipated at this time in an engine development program. The contractual requirements of Phase II-C along with the testing accomplished to date are shown in table 4.

Assembly and test of the three experimental JTF17 engines is well ahead of the program schedule as defined in the Detailed Work Plan for Phase II-C, PWA FR-1464A. Figure 6 is a comparison of the program schedule with the actual schedule accomplished. Figure 7 compares the estimated test time with the actual test time accomplished to date. The first engine was assembled and delivered to test 45 days ahead of the original estimated date. Testing began 31 March 1966. This first engine was assembled and tested with the duct heater installed. Augmented test time began on 5 April 1966. Testing at elevated turbine inlet temperature (at or above 2000°F) began on 22 June 1966, approximately 38 days ahead of schedule. Heated inlet testing began on 22 July 1966.

The condition of the engine parts following all engine builds has generally been excellent. Problems exhibited to date have been considerably fewer and less fundamental than usual for a new engine development.

The performance obtained on the JTF17 engine during 73.11 hours of testing is shown in figures 8, 9, and 10.

Table 4. Phase II-C Contractual Requirements and Testing Accomplished

Contractual Requirements	Phase II-C Status
Procure Parts for Three Engines	Completed
Assemble Three Engines	FX-161 and FX-162 Assembled FX-163 Build Date - September 1966
100 Hours of Test Time	73.11 Hours of Test Time Completed
Heated Inlet Time - 5 Hours	2.07 Hours of Heated Inlet Time Completed
Augmented Test Time - 5 Hours	15.65 Hours of Augmented Time Completed
2000°F or Higher Turbine Inlet Temperature Time	At or Above: 2000°F [illegible]8.38 hr 2200°F 4.07 hr 2300°F 0.59 hr

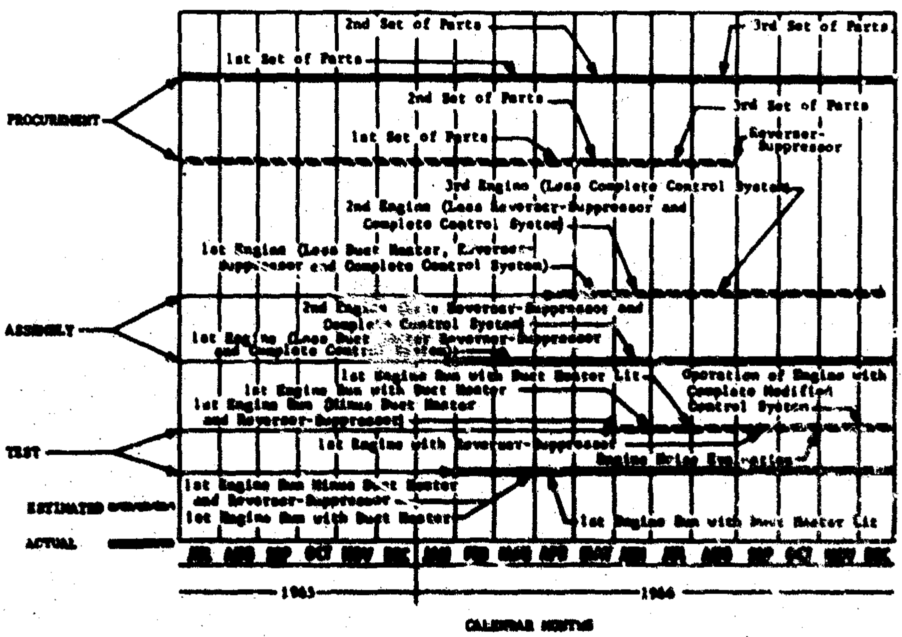


Figure 6. Phase II-C vs Predicted Accomplishments FD 17084 EIII

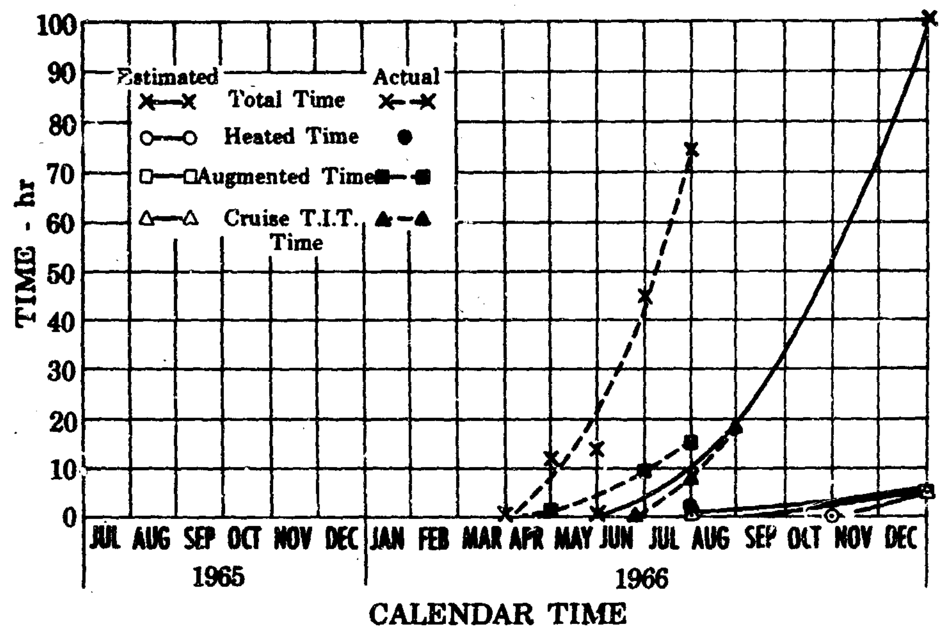


Figure 7. Comparison of Estimated Test Time and Actual Test Time FD 17087 EIII

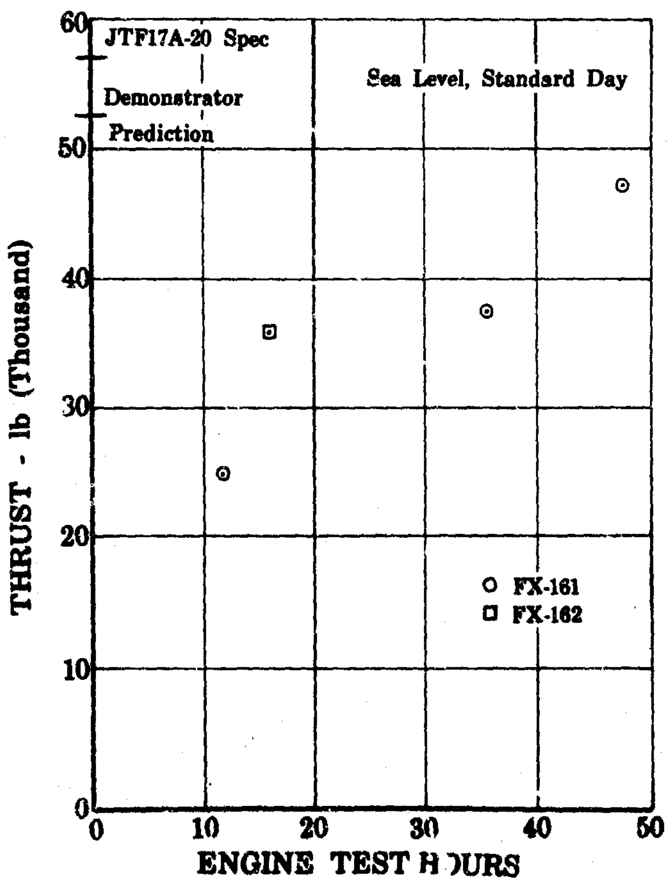


Figure 8. JTF17 Engine Performance vs Test Hours FD 17030 EIII

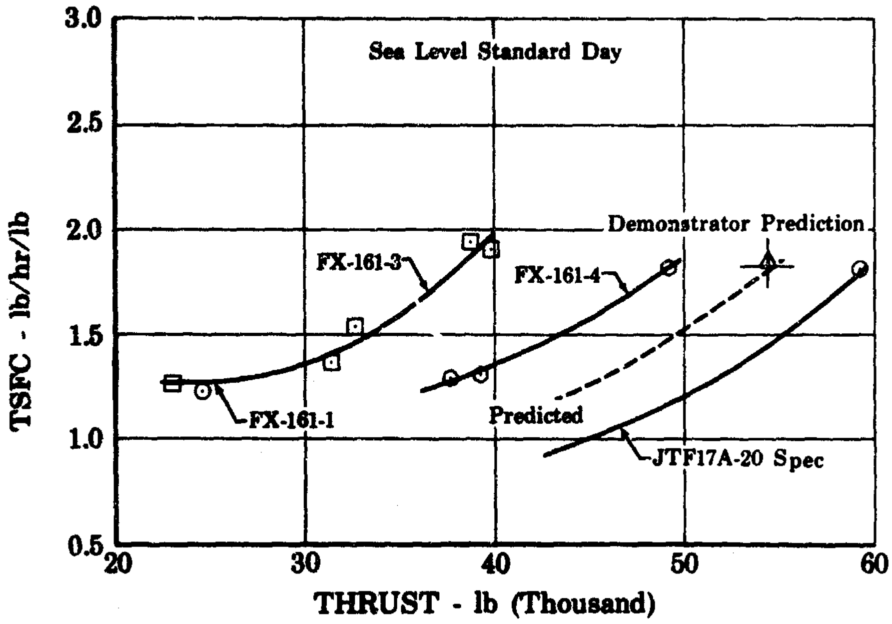


Figure 9. JTF17 Engine Performance - Duct Heater Lit FD 17031 EIII

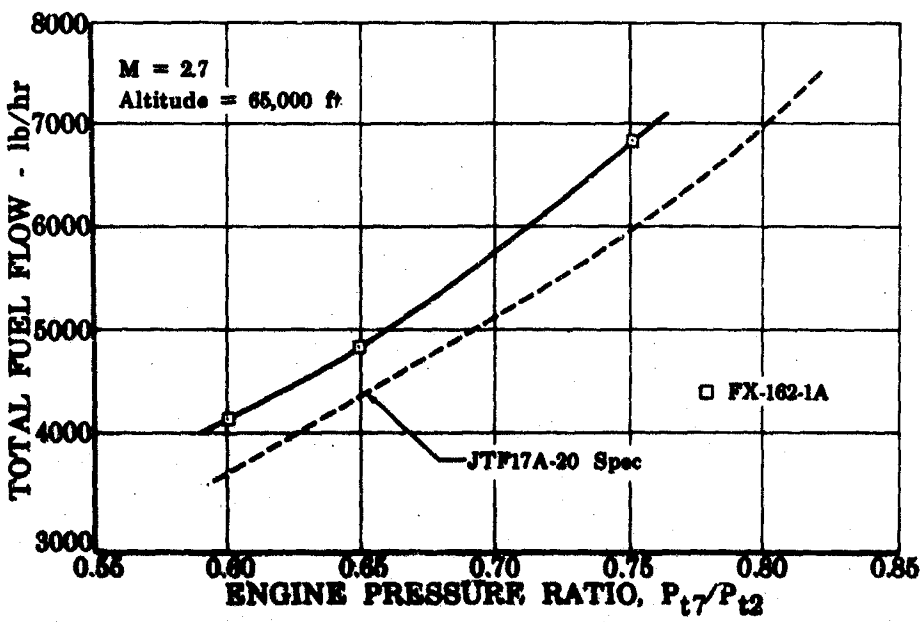


Figure 10. JTF17 Engine Performance - No Duct Heat FD 17032 EIII

2. Summary of Engine Builds

A brief summary of each engine build and its accomplishments follows:

a. FX-161, Build 1

This engine was assembled with the duct heater installed but minus the reverser-suppressor. The initial start was smooth and acceleration to idle speed was without event. A shakedown run and a performance calibration up to 90% high rotor speed including duct heater lit operation was accomplished. Figure 11 shows this engine mounted in a sea level test stand. Teardown inspection of the engine revealed all parts to be in excellent condition with the exception of the first stage turbine front seal. This seal developed cracks in the cylindrical section, as illustrated by figure 12. Analysis of the part indicated that the cracking was due to a high frequency resonance. Therefore, the seal was redesigned to incorporate a stiffener and a damper as illustrated by figure 13. Build Time on the engine was 11.63 hours.

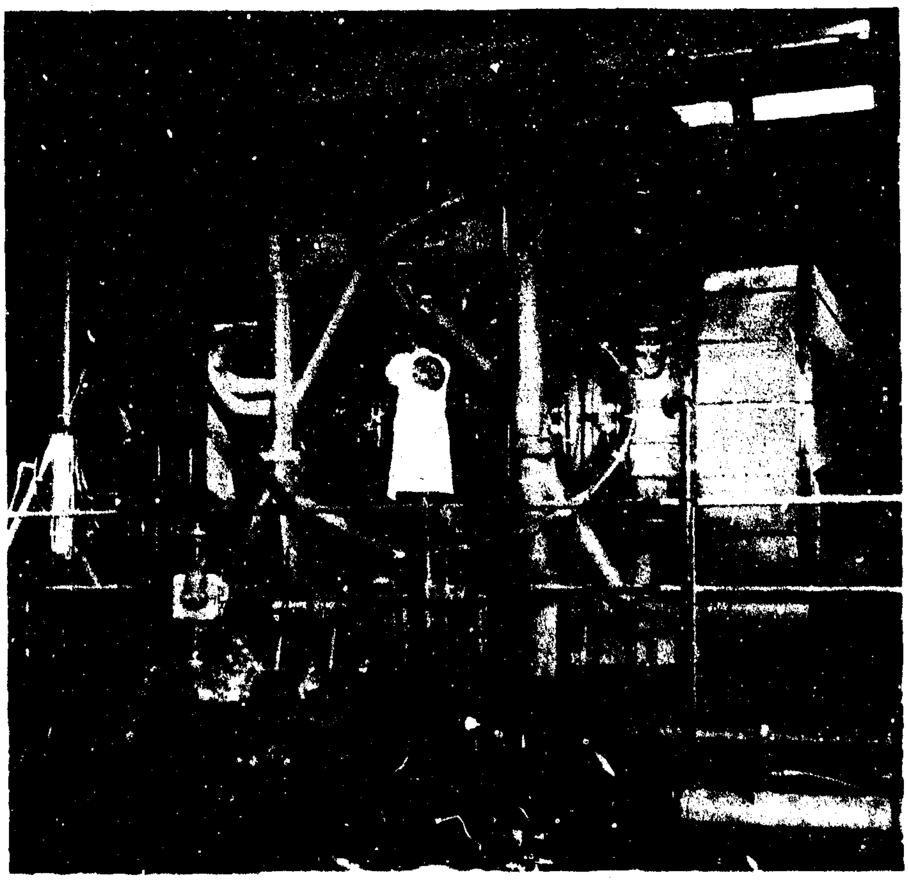


Figure 11. Engine FX-161, Build 1 Mounted in Sea Level Test Stand **FE 57509 EIII**

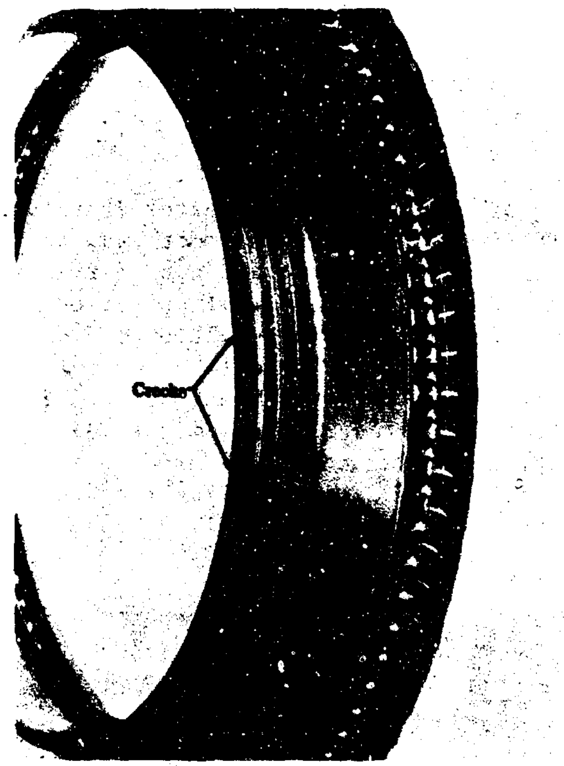


Figure 12. Labyrinth Air Seal Ahead of 1st-Stage Turbine Disk — FD 15615 EIII

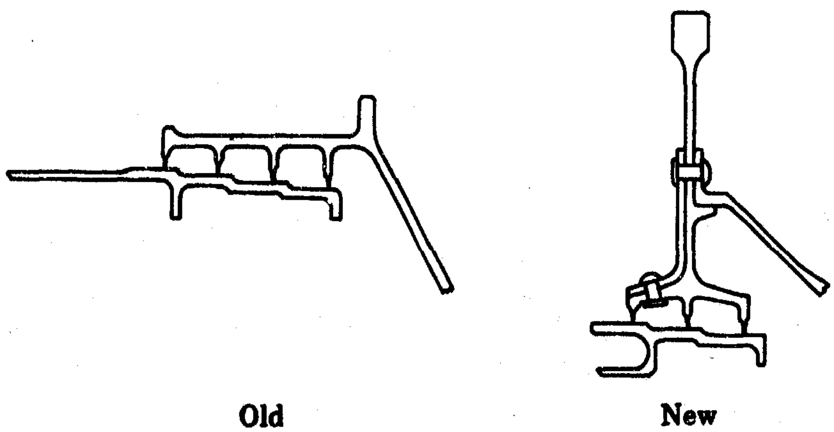


Figure 13. Comparison of New and Old Labyrinth Air Seal — FD 15903 EIII

b. FX-161, Build 2

The engine was rebuilt to the same configuration as Build 1 with the exception of the redesigned turbine seal. A sea level performance calibration was attempted with the high compressor bleeds open. However, the bleed air caused a severe maldistribution of inlet airflow to the main combustor and burning of the transition duct. Build time on the engine was 2.08 hours.

c. FX-161, Build 3

The bleed air system was revised to extract air from the leading edge of the main diffuser case struts. The transition duct was replaced and the engine was returned to test.

A complete sea level performance calibration was conducted up to 2100°F turbine inlet temperature and 96% rotor speed, including duct heater lit operation. A total of 22.22 hours of test time was accumulated on this build, including 107 calibration points. A program was conducted to define the compressor surge line. During this program, eight engine surges were encountered with no damage to the engine with the exception of loosening of the variable stator hinge pin clips. A redesigned retaining scheme was designed and installed on subsequent builds of the engine. The engine was removed from the test stand, after mapping out the high compressor operating range, to install a redesigned compressor. This redesigned compressor had been proven by rig test to have an improved surge line.

Good correlation was obtained between engine data and rig data for the surge line of the high compressor. Significant achievements of the build are:

Maximum demonstrated corrected thrust	38,750 lb
Maximum high rotor speed, % rated	96
Maximum turbine inlet temperature	2100°F
Time at 2000°F TIT or above	5.72 hr
Duct heater lit time	7.55 hr

d. FX-161, Build 4

The engine was rebuilt with the redesigned high compressor. A sea level performance calibration was run up to 2300°F turbine inlet temperature and duct heater lit operation. The operating line of the redesigned high compressor showed the predicted improved surge margin. A program was run to establish the surge line of the fan with test data correlating at test. Significant results of this build to date are:

Maximum demonstrated corrected thrust	47,500 lb
Maximum high rotor speed, % rated	95
Maximum turbine inlet temperature	2320°F
Time at 2000°F TIT or above	10.53 hr
Duct heater lit time	6.26 hr

e. FX-162, Build 1

Tests were conducted to determine starting and idle run characteristics. The engine lit on the first attempt and accelerated to idle smoothly. Additional tests were conducted to check the control schedules and automatic operation of the high compressor variable guide vanes. The vanes operated satisfactorily. The high speed operating characteristics of the fan, compressor, and turbine were then explored at two compressor bleed settings and two duct heater nozzle area settings. During this exploratory testing, three high compressor surges were encountered. The ram-induction primary combustor performed satisfactorily and provided an exceptionally uniform turbine inlet temperature. The duct heater was lit at a high rotor speed of 7500 rpm (92% of rated speed) and fuel flow increased to the design fuel/air ratio of 0.05. Ignition and operation of the duct heater was smooth. At these 92% speed conditions, the augmented thrust was 36,000 pounds.

Eight starts and one duct heater light, all of which were satisfactory, were completed. Engine vibration levels were low, bearing and oil temperatures were as expected, the burner discharge temperature spread was acceptable, and the level was uniform around the full annulus. Fan blade stresses, as determined with strain gages, were very low, with no indication of problem areas. The maximum turbine inlet temperature was 2115°F. The engine was removed from the sea level stand and mounted in an altitude test stand.

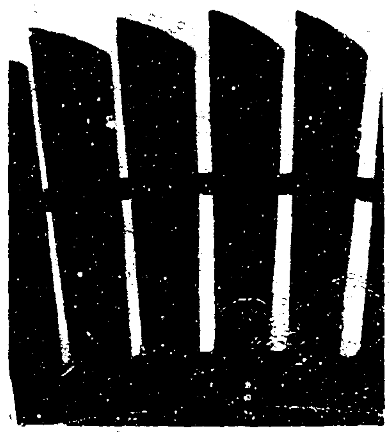
Sea level ram windmill tests and altitude ram windmill tests were conducted. Initial altitude engine run tests were conducted on 22 July 1966. The engine operated satisfactorily up to 96% of design rotor speed at cruise conditions. At 97% rotor speed, just prior to lighting the duct heater, high rotor vibrations occurred. A normal descent and shutdown were completed. The engine was removed from the test stand for complete disassembly and inspection. Total altitude test time was 2.07 hours, of which 1.65 hours were at cruise conditions (65,000 feet, Mach 2.7 ram inlet conditions).

Inspection revealed that two 3rd-stage compressor blades (first stage of the high compressor) had failed at a point one-third up from the platform, as shown in figure 14. Seven other blades were found to have cracks in the same general area. Later designed parts also shown on figure 14 had been installed in engine FX-161, Build 4. The failure is attributed to fatigue, resulting from bending flutter encountered in and near the compressor surge band. Excellent containment ability was demonstrated by the 3rd-stage honeycomb shroud. This engine is currently being rebuilt for additional testing.

f. Summation of Engine Characteristics

The engine has operated during this period free from major mechanical problems or discrepancies. Every engine start has been smooth and without incident. The oil consumption has been low and the bearing operating temperatures have been normal. The vibration levels are low and no increase has been observed after experiencing a surge on the engine. Duct heater lights have been performed at various speeds and air velocities through the duct (controlled by nozzle position). Lights have been obtained every time under each of these conditions and have been soft with no appreciable increase in fan back pressure or sound level.

Failed 3rd-Stage Compressor Blade



Midspan Shroud, 3rd-Stage Blade

Figure 14. Comparison of 3rd-Stage Compressor Arrangement — FD 16912 EIII

F. PHASE III DEVELOPMENT TEST PROGRAM

1. General

The objective of the Phase III and IV test programs is to develop the JTF17 engine to the level of performance required by the engine Model Specification with the durability and reliability needed for commercial service. Achievement of these objectives will be demonstrated by the completion of an engine Flight Test Substantiation test and an engine type Certification test.

Initial engine testing in Phase III will be conducted using the three JTF17 engines available from Phase II-C. These engines will be supplemented by additional development engines that have been fabricated to the later designs resulting from the Phase II-C effort. The three development engines completed in Phase II-C will be refurbished to the later design during Phase III. Approximately 12 development JTF17 engines will be active in the program through engine FTS and 15 engines through Certification. It is expected that approximately 4000 hours will have been accumulated by FTS and approximately 14,500 hours by engine certification.

The component and engine test programs are closely interrelated. One of the purposes of the engine test program is to continue the development of the components as an integrated part of the engine systems.

Engine testing will be conducted at sea level environmental conditions, with and without heated inlet air, and at simulated altitude conditions. Particular emphasis will be placed on tests with simulated operational environmental conditions, including the pressures, temperatures, and inlet distortion conditions anticipated during actual service use. The engine test facilities to be used during Phase III program are described briefly in Section I of this report and in detail in Volume V, Section XIII. The capabilities of the altitude simulation test stands C-4, C-6, and X-210 are shown in figures 15, 16, and 17. The following describes in detail the planned Phase III engine development test program.

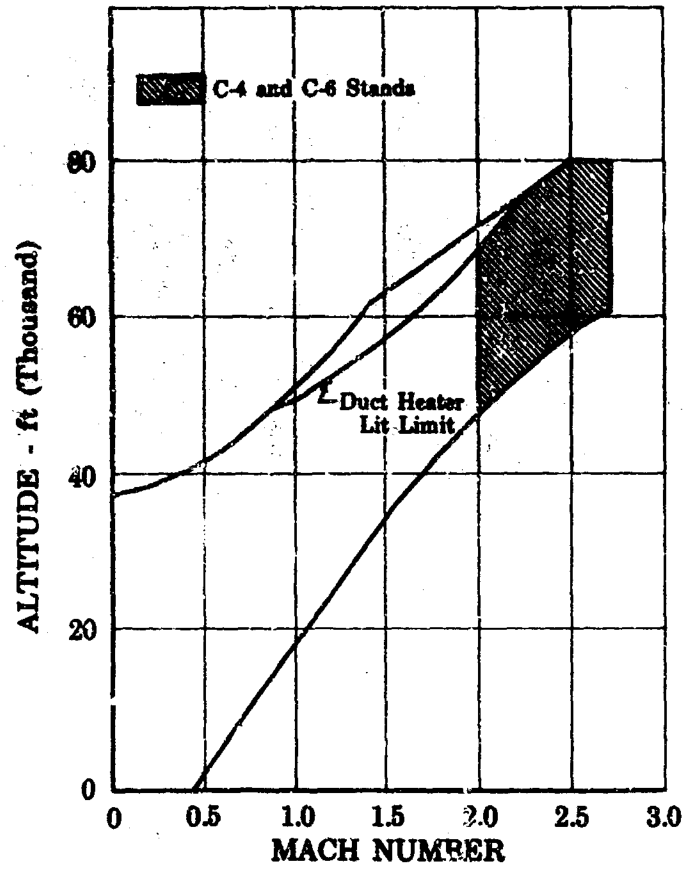


Figure 15. C-4 and C-6 Test Stand Capabilities FD 16663 EIII

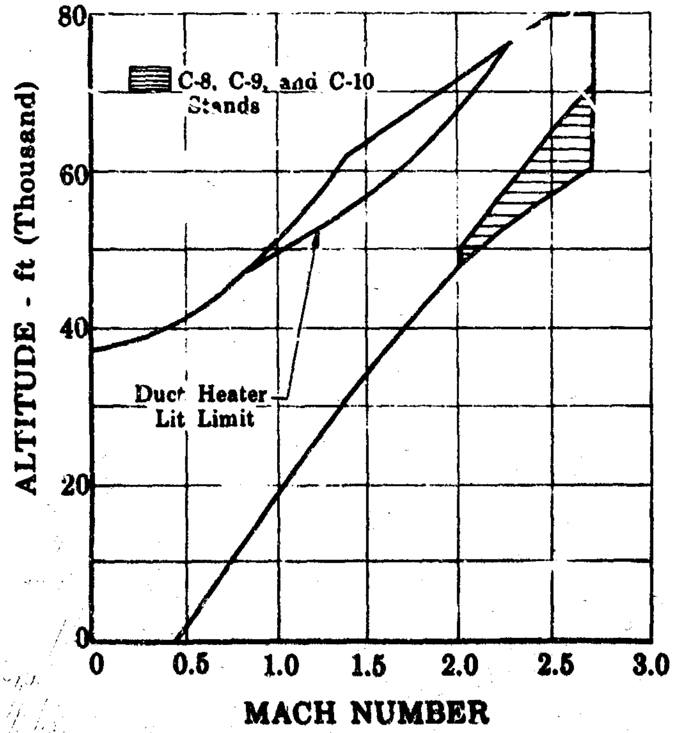


Figure 16. C-8, C-9, and C-10 Test Stand Capabilities FD 16787 EIII

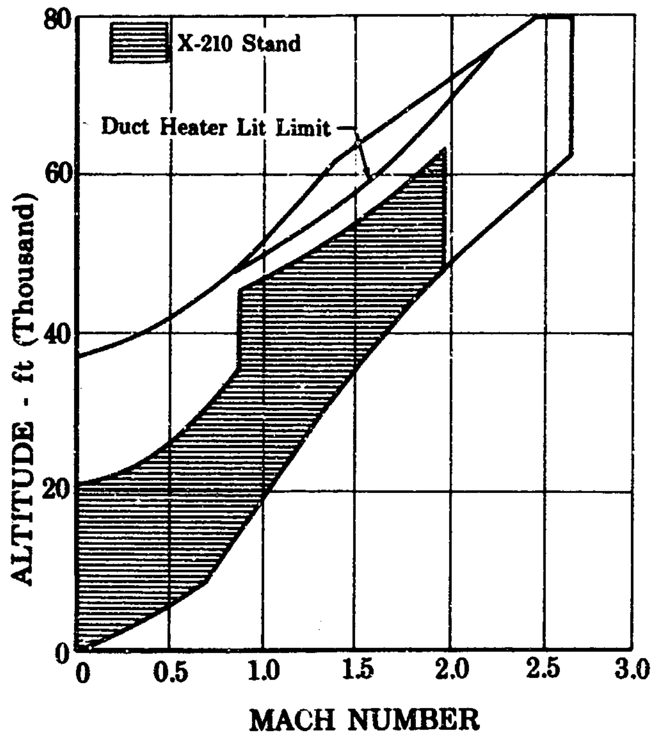


Figure 17. X-210 Test Stand Capabilities FD 16788
EIII

2. Performance Test Program

a. Sea Level Performance Testing

Sea level performance tests are used to determine basic engine performance and to evaluate the effect of engine changes. These tests consist of operating the engine at a series of steady state thrust levels at sea level static conditions. Tests are run with and without the duct heater lit. These tests are run with extensive instrumentation at each significant station, permitting overall engine evaluation and individual component evaluation. Instrumentation used in this testing is described in Section I of this report.

A complete set of data is taken at approximately equal increments of thrust from idle conditions to maximum nonaugmented thrust and at approximately equal fuel flow increments from minimum duct heater fuel flow to maximum duct heater fuel flow. Data obtained will be translated into overall engine performance and individual component performance with the aid of computer programs developed for the JTF17 engine program. The values of the parameters thus obtained will be analyzed for conformance to design goals and for indications of change in engine performance relative to a standard established by the same or similar engines. Particular attention will be given to those parameters related to the section of the engine where a change in parts has been made.

Where the engine performance does not meet design goals, data is analyzed to determine which component is deficient. Design changes are effected to correct the deficiency and evaluated by subsequent engine performance tests.

Sea level performance testing began with initial build of the first development engine in Phase II-C.

It is anticipated that 600 hours of sea level performance testing will be accumulated by FTS. It is to be noted that essentially all engine tests obtain some performance data. Figure 5 shows the planned Phase III sea level engine test program and the anticipated Phase IV program.

b. Altitude Performance Testing

As in the case of sea level performance testing, the altitude performance test is used to determine basic engine and component performance and to evaluate the effect of engine changes on performance. The test consists of setting a series of simulated subsonic, transonic, and cruise operation conditions which are consistent with the Engine Specification guarantees and representative of the airframe requirements. These tests are run in C-4, C-6 or X-210 test stands and with extensive instrumentation as described in Section I of this report. In addition to evaluating engine changes, the performance of the engine over the entire operating envelope will be determined, except as limited by the facilities being used. As in the case of sea level performance testing, altitude data will be analyzed for conformance to design goals. Where deficiencies exist, design changes will be effected and proven by subsequent engine testing.

Altitude performance testing began in July 1966. It is anticipated that 600 hours of altitude performance testing will be accumulated by FTS, however, all altitude testing obtains some performance data. Figure 5 shows the planned Phase III altitude performance engine test program and the anticipated Phase IV program.

c. Inlet Profile Effect Test Program

The engine Model Specification describes the engine inlet profile distortion levels that must be accommodated without performance loss. This distortion tolerance will be developed and verified by full-scale engine testing at sea level and altitude conditions during the proposed Phase III program.

Steady-state distortion testing will be conducted at sea level static conditions and at simulated subsonic, transonic, and cruise conditions which are typical of the climb, cruise, and descent path of the SST airplane. Transient testing will be conducted at sea level static conditions at FRDC. Transient testing at simulated flight altitude conditions will be conducted at the Arnold Engineering Development Center facilities. This testing is described in Report D, Inlet-Engine Compatibility program.

(1) Inlet Pressure Profile Distortion Program

Satisfactory engine operation will be developed and demonstrated at steady-state and transient conditions with distortion levels as specified above. Data will be obtained with inlet pressure profile distortion levels in excess of those specified to assure an adequate margin of confidence.

Two methods of providing controlled and reproducible amounts of inlet pressure distortion will be used in this testing. A distortion generator, as illustrated by figure 18, is capable of generating radial and circumferential

inlet pressure profile distortion will be used to establish the distortion tolerance of the engine and the effect of inlet pressure profile distortion on engine parameters such as fan and compressor airflow, turbine inlet temperature profile, and fan and compressor durability. The stability of the engine control system will also be determined by this testing. As soon as representative airframe inlet distortion patterns from model testing are adequately established, engine tests will be conducted with these patterns to verify the overlap of the engine distortion tolerance and the inlet distortion. To accelerate engine distortion testing over a range of corrected speeds typical of climb, transonic acceleration, and cruise, the development of a remotely variable distortion generator will be undertaken.

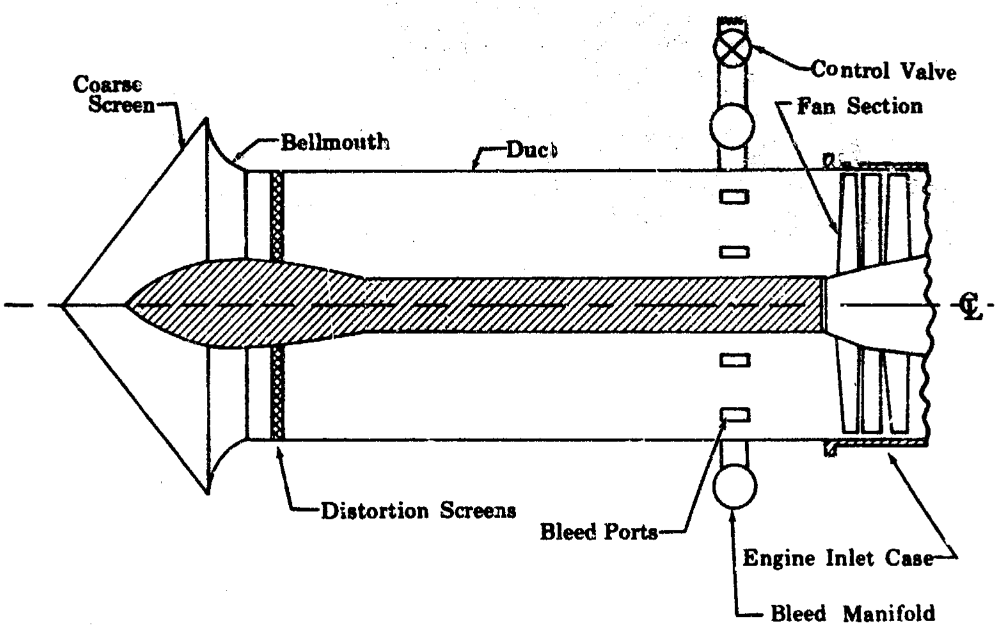


Figure 18. Distortion Generator

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EIII

The second system consists of a simulated airframe inlet that will duplicate, as closely as possible, the actual airframe inlet. In particular, items such as the supersonic-subsonic diffuser section, boundary layer control bleeds, and shock control system are duplicated. Testing with equipment of this type on the J58 engine at sea level conditions has proven that this type of simulation will permit accurate assessment of the major factors influencing engine-inlet compatibility as well as provide a quick and economical method of evaluating the effect of inlet aerodynamic changes on the engine. Figure 19 shows a J58 engine with a simulated inlet installed on a sea level test stand.

Initial testing will utilize a JTF17A-20 engine to obtain early recognition of potential deficiencies so that corrective action by the airframe and/or engine manufacturer can be initiated. A prototype fan will be installed and the turbines modified to obtain cruise aerodynamic conditions in the fan and high compressor while operating on a sea level test stand.

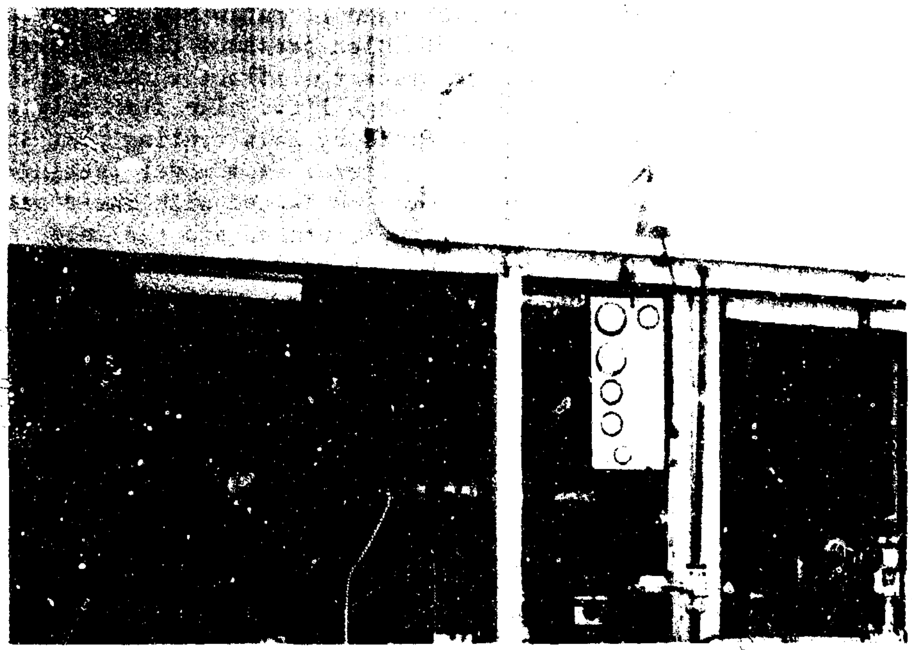

Figure 19. J58 Engine With Simulated Inlet Installed on Sea Level Test Stand — FE 60676 LIII

Extensively instrumented development JTF17 engines with Parts List aerodynamics configurations will be used for subsequent inlet profile distortion testing as outlined in the Inlet-Engine Compatibility program. Data will be processed by computers, and evaluated from an overall engine standpoint as well as individual component standpoint. Engine changes which affect inlet aerodynamics will also be evaluated by this method.

(2) Temperature Distortion

Engine testing will be conducted with various degrees of distortion of the inlet temperature profile to develop and demonstrate satisfactory operation and performance with inlet temperature distortion such as may inadvertently occur during reverser operation. Heated air will be obtained by deflecting air from the duct heater discharge and re-introducing it at the engine inlet. The position of the duct air return behind the duct heater discharge will be varied to adjust the inlet temperature pattern as required to simulate the predicted engine-airplane pattern. The test installation is shown in figure 20. A fully instrumented engine will be used for these tests, with special temperature instrumentation in the region of re-ingestion of air and in the fan and compressor sections. Data will be processed by a computer; the various engine parameters will be analyzed to determine the effect of temperature distortion. These data will determine whether any engine limitations exist. Engine changes will be made and evaluated where engine limitations may unduly restrict the airframe-engine combination as indicated from airframe reverser model wind tunnel tests.

d. Transient Test Program

Transient testing of the engine will be conducted at both standard and non-standard day conditions at sea level static and landing approach conditions typical of the SST. Parameters to be evaluated in this test program are engine

acceleration and deceleration response rates, control system stability during acceleration and deceleration and optimization of fuel control schedules and variable stator positioning considering compressor surge characteristics. The engine will be developed to provide the thrust response characteristics as outlined in the engine model specification. It is anticipated that 150 hours of testing will be accomplished by FTS, and 300 hours by the end of Phase III.

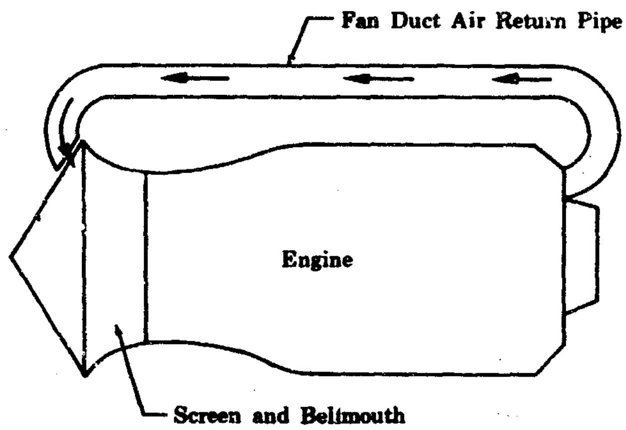

Figure 20. Method of Reingesting Fan Air To Produce Inlet Temperature Variations — FD 16790 BIII

Fully instrumented development JTF17 engines will be used in this test program with pertinent parameters being recorded by an automatic data recording system. Engine mounted transducers and quick response temperature and pressure sensing probes will be used. Oscillograph recordings and photo panel data will be taken as required to obtain the necessary data.

Data will be analyzed for conformance to design goals. Individual component data will be analyzed and corrective action effected where discrepancies are found. Corrective action for marginal thrust response of the engine could be a change to an improved stall line compressor developed by the component test program or the acceleration schedule of the main fuel control. The fuel control-engine matching will be accelerated by use of an automatic adjustable schedule fuel control simulator (DEBB) as described in detail in the Controls Section Volume III, Report B, Section III. A new cam, designed to correct the discrepancy, would then be procured, bench tested in a fuel control to determine that the design goal had been met, and engine tested in the same manner as the original test as final proof that design goals had been met.

3. Engine Systems Test Program

a. Engine-Inlet

The development of a compatible engine-inlet system is a prime requisite for the initiation of the flight testing of prototype SST aircraft and eventual certification of the engine-aircraft configuration. Prior to flight testing,

every effort must be made to duplicate the environment in which the total propulsion system must function to the maximum capability of test facilities so as to reduce the time and cost of the flight testing which will ultimately impose the true total dynamic environment on the engine-inlet combination. It is possible and necessary to investigate, both analytically and experimentally, the properties of the propulsion system that are of first order of importance in determination of system compatibility. These investigations, undertaken during Phase II-C and early in Phase III, serve to initiate compatibility development at a time when changes to improve compatibility between the components of the engine and inlet can be incorporated at less cost and within the time frame of the program. The more readily simulated compatibility criteria, such as engine-inlet profile pressure and temperature distortion, will be investigated in the least expensive type of test, described in the preceding section, and the information gained fed back into the development cycle quickly. In this way, any major deficiencies can be recognized and, if necessary, corrective action undertaken early enough to be included in the later tests of the component or engine. Plans for testing the JTF17 engine at FRDC with inlet profile distortion generators and with a simulated airframe inlet are described in paragraph 2c(1) of this report. In addition to this work, compatibility testing in the Propulsion Wind Tunnel at AEDC is planned to provide the maximum duplication of factors influencing engine-inlet compatibility. The plan for compatibility testing at AEDC is described in detail in Report D, Section II.

b. Fuel Control System

To ensure that the fuel control system and its various schedules perform the function for which they are intended, an estimated 1500 hours of testing will be conducted on engines in Phase III. These tests will be directed toward determining schedules for starting, acceleration, deceleration, governor hook slope, acceleration and steady-state bias, and power lever position versus thrust. Stability of all systems, such as the duct heater nozzle control and high compressor variable stator, will be demonstrated as well as reliability, durability, and maintainability of the control system.

Early Phase III engine testing will be supported by continued use of the development engine controls used in Phase II-C. Development engine control system components procured early in Phase III will be incorporated into the engine testing program at FRDC as soon as they have been thoroughly bench checked. In addition to supporting the engine development test program, the prototype engine fuel, hydraulic, and ignition systems must undergo engine development tests to establish the capability of each of these systems to properly control the engine under the variety of flight and environmental conditions it will encounter. The following engine control system development tests will be accomplished; the estimated test engine hours are shown in figure 5.

1. Cold gas generator starts under conditions of low temperature engine, air and fuel typical of the SST airplane subsonic hold conditions will be run in X-210 stand. These tests will demonstrate the capability of the ignition system to light the engine under cold conditions as well as the capability of the control system to accelerate the engine to idle under these conditions. These cold starts will be accomplished with one and/or two gas generator igniters firing to demonstrate the redundancy of the ignition system for cold engine starting.

2. Gas generator starting characteristics will be evaluated and improved as necessary to meet the flight envelope requirements. These tests will demonstrate gas generator relight capabilities of the ignition system at selected conditions, within the facilities capability, throughout the engine flight envelope, including windmilling relights through 80,000 ft altitude and Mach 2.7. These tests will be performed with one and with two igniters firing. Tests will be conducted in C-4, C-6, and X-210 test stands. It is anticipated that approximately 300 relights will be accomplished in this relight program. Corrective action, such as a redesign of the spark igniters, or changes to the combustor to enhance ignition, will be taken as required until satisfactory relight capabilities are obtained and demonstrated.

3. Duct heater ignition capability within the engine operating envelope will be developed and demonstrated. These tests will demonstrate duct heater ignition capabilities at selected conditions within the facilities capability throughout the engine flight envelope, including windmilling relights through 80,000 ft altitude and Mach 2.7. These tests will be performed with one and with two igniters firing. Tests will be conducted in C-6, and X-210 test stands. It is anticipated that approximately 200 duct heater lights will be accomplished in this ignition program. Corrective action, such as redesign of the igniters or combustion chamber, will be taken as required until satisfactory start capabilities of the duct heater have been developed and demonstrated.

4. Engine testing of the control system throughout the flight envelope at airframe nacelle airflows, pressures, and temperatures, with cold and hot fuel, will be accomplished in C-4, C-6, and X-210 test stands. This testing will verify fuel system temperatures at various engine operating conditions and will provide development testing of the fuel control system components toward elimination of any temperature (ambient and/or fuel) effects on the control system that might cause a variation in engine performance such as fuel schedule variations, response rate variations, and variations in control system stability. Specific controls development programs resulting from the above surveys will be accomplished as required.

5. Engine-control system interface effects, plus certain engine-airframe interface effects on the control system, will be investigated. These interface effects tests will be accomplished at sea level ambient conditions as well as at simulated conditions of altitude and Mach number. These tests will determine control system and engine response rates, system and subsystem damping, control system engine and subsystem stability, tendencies to overshoot during rapid transients, and the effect of engine inlet distortions in temperature and/or pressure on control system engine operation. Engine and control system response rates to changes in power lever position, the effect of engine burner pressure rate of change and pulsations on the engine-control system operation, and the effect of rapid changes in compressor inlet temperature on the engine-control system operation will be investigated during this phase

of engine testing. Testing with a simulated airframe fuel supply system including boost pumps, supply lines, and heat exchanger volumes will be conducted. Compatibility testing with the airframe fuel system has been found to be a valuable and necessary item in the development of the J58 engine and commercial Pratt & Whitney Aircraft engines. Compatibility testing will begin as soon as the airframe prototype fuel systems are firm. The complete airframe fuel system, including pumps, filters, screens, plumbing size and length, etc., will be duplicated on a sea level test stand. The effect of the following items on the fuel control and engine systems are among those to be evaluated:

(a) Air entrainment in the fuel system
(b) Contamination of the fuel by such items as sand, lint, etc.
(c) Failure of airframe fuel supply pump
(d) Intermittent loss of fuel supply pressure.

6. Maintainability of control system components will be developed and demonstrated through removal and replacement of components in conjunction with engine test programs.

7. Control system component endurance capability will be demonstrated by engine testing. This will be a factor in every engine test accomplished as well as in specific engine tests run to demonstrate overall engine endurance and performance capabilities, such as FTS and Engine Certification tests.

4. Engine Subsystem Integration Validity Tests

The test program described in Section II of this report is an integral part of the overall engine development program to develop desired levels of performance and durability of the various major components and their subsystems. However, there is no substitute for full-scale engine testing. The interdependence of component subsystems and the matching of these subsystems must be evaluated in full-scale engine testing over a wide range of environmental conditions.

The engine test program of subsystem integration for the JTF17 engine includes the fan, high compressor, main combustor, turbine, etc., as well as the internal systems of the engine, such as the main bearing thrust balance system, internal cooling system, bearing compartment seal pressurization and vent system, and the lubrication system. It is anticipated that 1055 hours of full-scale engine testing will be devoted to such subsystem evaluation and development by FTS and 2180 hours by the end of Phase III.

a. Fan Testing

The full-scale engine testing directed toward development of the JTF17 fan includes both aerodynamic as well as structural testing. The aerodynamic testing will include verification of surge line and efficiency levels, and speed-flow relationship for the gas generator side and duct portion of the fan. These data will confirm results determined during testing of the fan rig as described in Section II. The structural testing consists of determination of stress and

temperature levels of rotating as well as stationary parts of the fan over the entire engine operating envelope, except as limited by test facilities capability This testing is verification of the data obtained in the fan rig testing. Pressure has been measured upstream of the duct heater in rig tests. Data from these measurements demonstrate that using a modulated reset variable jet nozzle results in soft duct heater lights. As a result of these soft lights, duct heater operation has no effect on the fan match point. Engine tests will be conducted to confirm these data. Other variables will include the N_1 - N_2 transient speed-flow operating line during a snap acceleration to verify analog simulations.

(1) Aerodynamic Testing

Extensively instrumented development engines will be used for aerodynamic testing. Testing will be conducted primarily on a sea level stand to evaluate fan part changes. Changes that are promising will be evaluated in the altitude test stands at simulated flight conditions. Testing will be conducted with various duct heater and gas generator nozzle areas over the full power operating range of the engine, thus allowing fan performance to be mapped out as shown in figures 21 and 22.

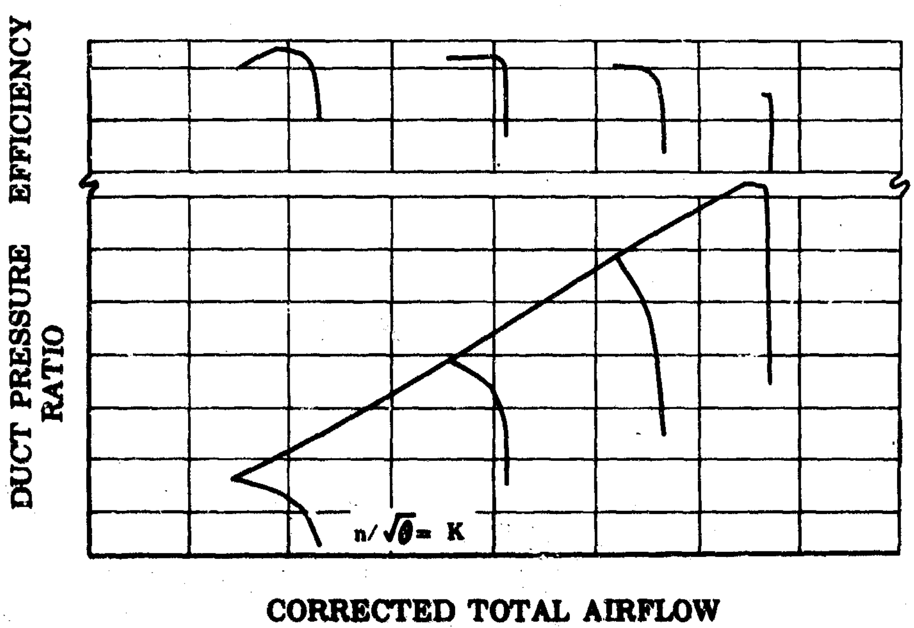

Figure 21. Duct Stream Performance FD 17086 EIII

The data obtained from this testing will be reduced to gas generator performance parameters with the aid of the computer program developed during Phase II-C. These data will then be evaluated for adequacy of surge margin, efficiency levels, and speed-flow relationships. Redesign, test, and evaluations are conducted in a continuous cycle until design goals are achieved.

The performance decrement attributed to service repair limits, blade and vane erosion, etc., will be determined in this program. These data will establish realistic service repair limits for the JTF17 engine.

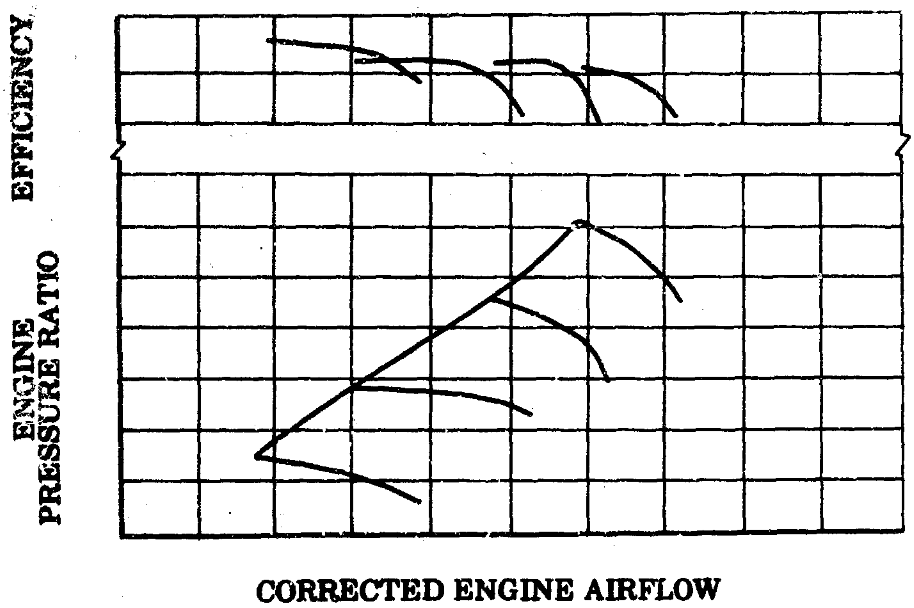

Figure 22. Engine Stream Performance FD 17085
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(2) Structural Testing

Experimental engines with instrumentation as described in Section I will be used for structural testing of the fan in support of the component test program. However, additional instrumentation in the form of thermocouples and strain gages will be applied to structural cases, disks, blades and stators to verify that vibratory stress and temperature levels of all structural engine parts are within acceptable limits. The rotating strain measurements and/or temperatures are taken by means of a slip ring assembly and are reduced to engineering units by computer programs already developed during the J58 and Phase II-C programs. These data are evaluated for conformance to design limits. Redesign, test and evaluations are conducted in a continuous cycle until desired durability is achieved.

b. High Compressor Testing

As is the case of fan testing, full-scale engine testing of the high compressor includes both aerodynamic and structural testing. Fully instrumented development engines will be used. Aerodynamic testing includes verification of surge line, efficiency levels, speed-flow relationships and variable stator schedule. The engine test data will be compared to that determined by the full-scale rig testing described in Section II. Structural testing includes determination of stress and temperature levels of rotating and stationary structural members of the high compressor over the entire operating envelope of the engine, except as limited by the facilities. Interactions of other engine subsystems with the high compressor, such as the fan inner discharge pressure profile (high compressor inlet), will be evaluated in this phase of testing.

(1) Aerodynamic Testing

An instrumented engine as described in Section I will be used in this testing. Testing will be conducted primarily on a sea level stand, and promising

configurations will be evaluated at environmental conditions. High compressor parameters such as speed, airflow, pressure rise, and temperature rise will be recorded for steady-state conditions over the engine operating range to allow high compressor performance to be mapped out as shown in figure 23. Transient operation will verify fuel control schedules and biases and the matching of the fan and high compressor operating characteristics.

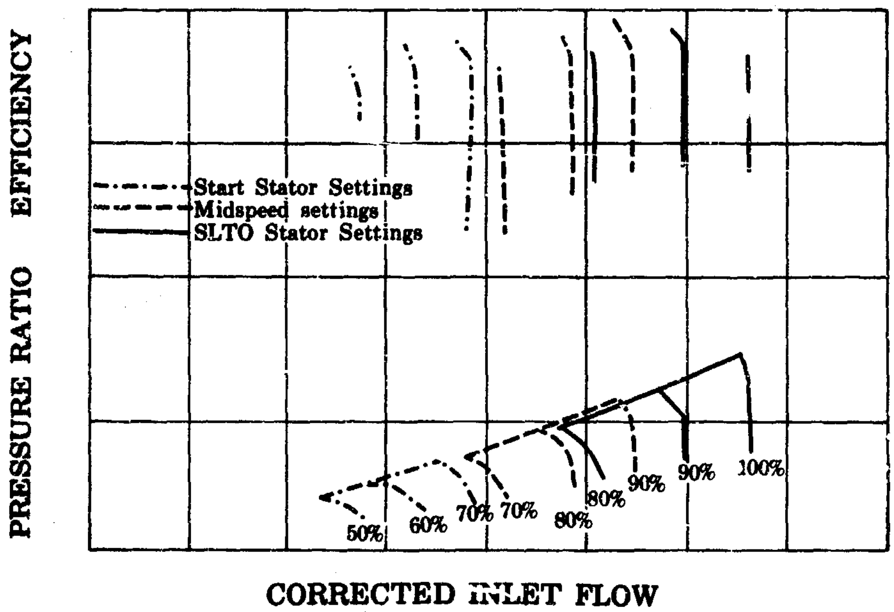

Figure 23. High Pressure Compressor Overall Performance Map FD 16662 EIII

The data obtained will be reduced by already developed computer programs and evaluated for adequacy of surge margin, efficiency level, speed-flow relationship, and variable stator schedule. The effect of inlet distortion on the high compressor, if any, will be determined as described in Distortion Testing and Engine-Inlet Compatibility testing. The effect of bleed air and horsepower extraction will also be evaluated.

The performance decrement attributed to service repair limits, blade and vane erosion, etc., will be determined in this program. These data will help establish realistic service repair limits for the JTF17 engine.

(2) Structural Testing

An instrumented development engine will be used in this testing. However, additional instrumentation in the form of thermocouples and strain gages will be applied to the structural cases, disks, blades, stators, etc., to verify that vibratory stress and temperature levels are within acceptable limits. The rotating instrumentation is taken by means of an intershaft slip ring or telemetry system as described in Section I. Data obtained is reduced to engineering units and evaluated for conformance to design goals. Redesign, rig testing, and engine evaluations as necessary to correct deficiencies will be conducted.

c. Primary Combustor Testing

Tests at sea level and simulated altitude conditions will be conducted on development engines instrumented for performance to develop and measure primary combustor performance. Particular attention will be paid to combustor exit temperature and pressure instrumentation. This test program will determine the combustor pressure loss, radial and circumferential exit temperature pattern, fuel nozzle performance (carbon formation, spray pattern, internal coking, etc.) ignition characteristics, combustion efficiency, smoke generation and structural integrity.

Data will be obtained at sea level, subsonic, and cruise conditions to determine combustor performance over the engine operating range. Altitude relight capabilities with one and two igniters operating will be defined over the engine operating envelope except as limited by facilities.

Traverse programs will be conducted to establish compressor discharge profiles of pressure, temperature and velocity, and main diffuser case aerodynamics to ensure satisfactory and stable entrance conditions to the main combustor at all operation conditions.

For all combustor testing, the fuel supply temperatures expected at in-flight conditions will be duplicated. This testing will determine the extent of coke formation in the fuel system and carbon formation in the combustor itself.

Inlet profile distortion testing with conditions duplicating those expected at the discharge of the airframe inlet, will be conducted in this program to establish its effects on combustor performance and turbine inlet temperature variations.

Data from this program will be obtained on automatic data recording systems, reduced to engineering units by an electronic computer, and evaluated by comparison of calibrations before and after each change. Each change will be evaluated at typical transonic and cruise conditions in a fully instrumented engine incorporating special instrumentation similar to that employed during sea level engine tests. Data will be evaluated in a like manner.

d. Turbine Testing

Tests at sea level and simulated altitude conditions will be conducted on development engines. These engines will be fully instrumented for performance. In addition special instrumentation for interstage data will be included. The test program will include aerodynamic performance, structural tests, and heat transfer tests.

(1) Aerodynamic Performance

A fully instrumented development engine equipped with pressure and temperature instrumentation at the turbine inlet, turbine exit, and at the interstage (high rotor exit) position will be used in this program. Data will be obtained on the sea level stand over the engine operating range from idle to maximum thrust. Among the items to be evaluated by this program are the effects on turbine performance of rematched turbine nozzle areas, solidity, restagger, recamber, tip clearance, quantity of cooling air, method of cooling air recntry, and service rework limits.

Data from these tests will be taken on automatic data recording systems, reduced to engineering units by an electronic computer, and evaluated by comparison of calibrations before and after each change. Each change will be evaluated at typical transonic and cruise conditions in a fully instrumented engine containing the special instrumentation as the sea level test engine. Data will be evaluated in a like manner.

(2) Structural Tests

Instrumented engines will be used in this program, with special instrumentation installed to measure stress and temperature levels of structural cases, disks blades, spacers, shafts, etc. These data will be used to verify that vibratory stress and temperature levels are within acceptable limits. Data from rotating parts will be taken by means of intershaft slip rings or a telemetry system as described in Section I. These data are recorded by an automatic data recording system and reduced to engineering units by computer programs already developed during J58 and Phase II-C. Data are then evaluated for conformance to design goals. A cycle of redesign, test and evaluation is conducted until goals are met.

Testing in a full-scale engine will be supplemented by similar data taken on the High Spool Rig as described in Section II Component Development Test Plan.

(3) Heat Transfer Testing

Testing will be conducted in a full-scale engine at sea level and simulated cruise flight conditions to obtain heat transfer data for the turbine airfoils. These data are to verify the data obtained in turbine rig testing described in Section II. Special instrumentation will be incorporated in this engine to record parameters such as cooling air temperature and flow to each stage, and metal temperature of the airfoils at several radial and axial locations. Data will be obtained at both steady-state and transient conditions. These data will be recorded by an automatic data recording system, reduced to engineering units by an electronic computer, and evaluated for conformance to design goals. The effect of changes to airfoils, cooling air flows and other turbine section parameters on turbine performance and durability will be evaluated by comparison of data before and after the change. Changes are evolved, rig tested and evaluated on the engine until goals are met.

e. Duct Heater Testing

Testing will be conducted at sea level and at simulated subsonic, transonic, and cruise flight conditions using an instrumented development engine. Additional instrumentation will be incorporated in the duct heater section. This will include case and liner metal temperature, accelerometers and pressure and temperature traverse equipment at the duct heater exit.

The test program will be conducted at steady-state and transient conditions at sea level and simulated flight conditions. During the initial portion of this testing, a development fuel control system with independent control of the Zone I and Zone II duct heater fuel flows, and a manual control system for the nozzle will be used. Later in the Phase III program, when the flow splits and nozzle positions have been determined, the complete automatic fuel control system will be used. Evaluations will be conducted initially at sea level conditions; those

configurations and control settings which show merit will be evaluated at simulated flight conditions. Items to be evaluated are:

1. Pressure Loss
2. Smoke Generation
3. Ignition Capabilities
4. Blow-out Limits
5. Augmentor Nozzle Response
6. Noise Suppression
7. Case and Liner Operating Temperatures
8. Inlet Diffuser Performance as Influenced by the Fan Discharge
9. Stability of Combustion
10. Structural Integrity

Data obtained in this program will be recorded on an automatic data recording system, reduced to engineering units by an electronic computer, and evaluated for effects of changes, adequacy of performance data, and conformance to design goals. Rig, control, and engine development testing will be integrated to achieve the performance and durability goals.

f. Reverser-Suppressor Testing

The reverser-suppressor will be tested on an engine with instrumentation to measure pertinent parameters concerning the reverser-suppressor. The test program will include structural testing, forward and reverse thrust performance, and noise suppression tests. The reverse thrust and noise suppression evaluation will be conducted on a sea level stand. The ejector system cannot be properly operated at subsonic, transonic, and supersonic flight conditions unless altitude ambient pressure is attained. Since no facilities that can run these conditions with the reverser-suppressor on the engine are available without major modifications, complete performance testing of the ejector system is not currently planned in the engine test program. Performance will be established at sea level conditions and will be extrapolated to flight conditions by utilizing scale model data as described in Volume III, Report A. A performance validity test will be conducted at AEDC in January 1969. The 100-Hour Flight Test Program will also provide data on reverser-suppressor performance as discussed in Section V of this report.

(1) Structural Testing

Structural testing of the reverser-suppressor will be conducted on a sea level stand with appropriate measurements of skin temperatures, airflow, vibration and actuation of the reverser clamshells, blow-in doors, etc. This testing will be conducted on a development engine with duct heater lit and not lit, and with and without reverser operation. Data will be obtained over the full power range of the engine in both forward and reverse thrust modes of operation.

(2) Reverse Thrust Performance

1. Reverse thrust performance will be evaluated on a sea level stand. The engine will be tested over the full range of reverse thrust operation with measurements being made of reverse thrust level, response time, effective flow area, and rearward clamshell door leakage.

2. An internal performance validity test will be conducted at Arnold Engineering and Development Center starting in January 1969. Performance testing will be conducted at Mach number 2.7 at 65,000 feet altitude. The test will be conducted in J-1 stand and will encompass approximately 20 hours of test time. Stand occupancy is estimated to be two months.

The approximate schedule for this testing is as follows:

Item	Timing
Preliminary planning conference outlining preliminary designs and test objectives	1 year before start of test
Detail design and interface coordination	6 months before start of test
Detail test plan complete	3 months before start of test
Engine and associated hardware shipped	6 weeks before start of test
Start mounting engine	6 weeks before start of test
Stand occupancy	January, February of 1969

J-1 test stand is a tank type stand 16 feet in diameter and 29 feet in overall length with test capabilities from 0 to 3.3 Mach number and a pressure altitude range of 0 to 80,000 feet. The test point of Mach number 2.7 and 65,000 ft altitude is well within the capabilities of J-1 test stand. (See figure 24.)

Pratt & Whitney Aircraft will provide transport stand, bellmouth, ground handling fixtures, instrumentation probes, vibration pickup brackets, and other special test items required to support this test. Included in the support items are adapting facilities items such as the supersonic exhaust diffuser.

Data obtained will be evaluated for conformance to performance objectives and airframe requirements.

(3) Noise Suppression

The complete engine with the reverser-suppressor installed will be calibrated at sea level conditions to establish the octave band noise levels at engine thrust levels equivalent to takeoff, climb, approach, and taxi conditions of the SST. Perceived noise levels will be determined over the complete operating range from idle to sea level takeoff conditions. A complete description of this testing and methods of analysis is contained in Volume III, Report C.

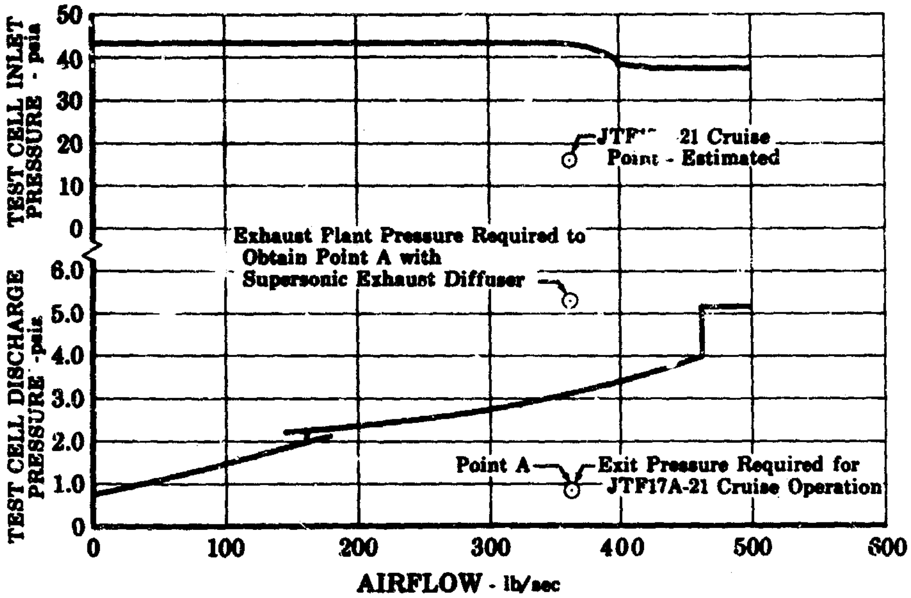

Figure 24. Estimated Air Supply and Exhauster Performance FD 17627 EIII

g. Gearbox Testing

The majority of the gearbox development testing will be conducted on gearbox rigs and is described in Section II of this report. However, during the engine development program, the development engines will incorporate the parts list gearboxes. Fuel and lubrication system components, such as main pump and control and the hydraulic pump, will be mounted in their normal manner on the engine gearbox, imposing design loads on the gearbox. Since engine development testing is to be conducted over the entire engine operating envelope, except as limited by facilities, the gearbox will be subjected to environmental testing under loaded conditions over the engine operating envelope. Included in this testing will be compatibility testing of the gearboxes with airframe-supplied components.

h. Lubrication System Testing

The engine lubrication system provides adequate lubrication and cooling to each of the engine bearing and seal compartments. Items to be evaluated in the lubrication system include oil consumption, seal wear, heat rejection including maximum fuel and oil temperatures, effect of heatshielding, fuel-oil cooler performance, and oil deterioration and coking to confirm tests conducted on bearing and seal rigs and the oil system simulator described in Section II. As a part of the planned engine performance and endurance program, measurements to determine these values will be taken. Oil interruption tests will also be conducted. These tests are described below:

(1) Oil Flow Interruption Tests

A development engine assembled to the JTF17 parts list will be subjected to 30 seconds of engine operation at low main oil pressure (substantially below 40 psi), followed by a 10-hour endurance test at sea level takeoff power conditions to demonstrate integrity of the lubrication system.

(2) Heat Rejection Tests

To evaluate the heat rejection characteristics of the lubrication system, development engines will be instrumented to determine the lubricant, metal, fuel, and environmental temperatures throughout the fuel and oil system of the engine. This program will be conducted throughout the Phase III development program and will be accomplished in conjunction with other programs at sea level, subsonic, transonic, and cruise conditions. Design changes evolved from this program will be tested and evaluated until the oil system will perform properly in flight engines.

i. Instrumentation Testing

Vibration testing will be conducted on engine components and cases to verify that they are free of destructive vibrations at steady-state and transient conditions throughout the engine operating range. The effects of inlet profile distortion on engine vibration will be evaluated in this program. As soon as the inlet distortion levels of the SST are adequately defined, vibration tests with these levels will be conducted. Engine linear vibration will be monitored constantly throughout the development program and the flight test program. Extrapolation of this data will verify critical speed calculations.

Engine testing will be conducted with engine instrumentation installed and recorded to establish the reliability and accuracy of the units and their possible effect on durability or performance of the other engine parts. These will include:

1. N_1 speed pulse generator
2. N_2 tachometer
3. Turbine exhaust average pressure
4. Turbine exhaust average temperature
5. Turbine exhaust individual probe average temperature
6. Duct heater nozzle position indicator
7. Oil pressure transducer
8. Oil temperature thermocouple
9. Oil level indicator
10. Low oil level warning indication
11. Oil filter pressure drop indication
12. Gas generator fuel flow meter
13. Duct heater fuel flow meter
14. Fuel pump inlet fuel temperature thermocouple
15. Fuel pump inlet fuel pressure transducer
16. Windmill brake position indicator
17. Thrust reverser clamshell position indicators
18. Gas generator fuel filter pressure drop indication

Monitoring points for future Aircraft Integrated Data Systems will be established, in part, by this program.

j. Main Bearing Thrust Balance System Testing

The main bearing thrust balance system is designed to provide a positive thrust load on the main thrust bearings under all normal engine operating conditions. This system consists of a pressure balance system utilizing the areas of compressor

and turbine disks for force pistons. The thrust load on the main bearings can be determined by measurement of critical pressures throughout the engine and/or the direct measurement of the reactive force of the bearing to its support structure. Both systems will be used in this program to verify that the engine thrust bearing loads are within design limits over the entire engine operating envelope. If overload or skidding conditions occur, appropriate changes will be made and evaluated by test until satisfactory operation is obtained. The engine testing will be correlated to the bearing tests described in Section II. Corrective changes evolved from the rig tests for bearing, support, or oil system will be engine tested to determine their validity.

k. Starting Tests

Starting tests will be conducted on the JTF17 engine under normal ambient conditions. This testing will be conducted on a sea level test stand and will include evaluation of the effect of variable stator schedule, bleed schedule, fuel control flow schedule, and augmentor nozzle schedules on engine starting characteristics.

A development JTF17 engine will be instrumented for gas generator performance, and starting tests will be conducted on a sea level test stand. Special instrumentation will be included to measure the following parameters; starter torque, starter air pressure and temperature, variable compressor vane angle, and timing sequences such as ignition timing, time from lightoff to idle, etc.

Engine torque-speed curves will be determined from this testing and the schedules for the fuel control, variable stator, and inter-compressor bleeds will be optimized. The data will provide evaluation of general starting performance and agreement with curves in the Engine Model Specification.

(1) Windmill Test

Instrumented engines assembled essentially to the JTF17 parts list will be used in this test program. The windmilling characteristics of these engines will be measured at selected points in the operating envelope of the engine. These selected points will be representative of the SST flight conditions and will include subsonic, transonic, and cruise conditions. Windmill tests at cruise conditions will include aerodynamic brake on and off conditions.

The subsonic portion of the operating envelope will be run in Pratt & Whitney Aircraft's Willgoos Laboratory in East Hartford. The transonic and cruise portions will be run in the altitude facilities at FRDC. Data from this program will include windmill drag and rotor speed data to determine heat rejection at cruise conditions with aerodynamic brake on and off. The heat rejection data will help define the engine limitations under windmilling conditions.

5. Endurance Test Program

Engine durability and reliability leading to long Time Between Overhaul (TBO) can only be achieved through many hours of endurance testing during the development of the engine. Several types of endurance testing have been utilized at Pratt & Whitney Aircraft during the development of the J58 engine and long-life commercial engines such as the JT8D, JT3D, and JT4 engines and will be used in the Phase III JTF17 program. These endurance tests include:

1. Typical SST Mission Cycle Endurance
2. Low Cycle Fatigue Testing of Turbine Airfoils
3. Thermal Fatigue Cycle Testing of Rotating Parts
4. Company FTS Endurance

a. Typical SST Mission Cycle Endurance

Fully instrumented development engines assembled essentially to the JTF17 engine parts list will be used in this test program. A complete performance calibration is conducted on a sea level stand prior to endurance. The endurance program for the engine is patterned after the typical flight plan of an SST and will be amended, as necessary, as the SST flight plan is further defined. The test program is conducted under environmental conditions in a sea level, heated inlet test stand. The proposed mission endurance cycle is shown in figure 25.

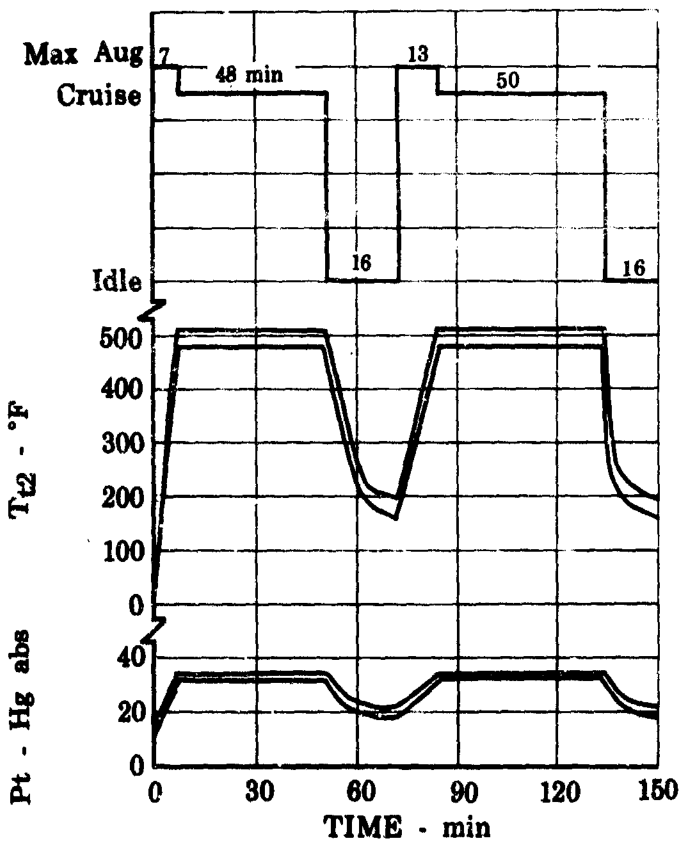

Figure 25. Mission Cycle Test

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Mission cycle testing will begin as soon as development testing indicates that a satisfactory level of engine performance and durability has been achieved. The initial endurance program will encompass several builds of the engine with appropriate hot section inspections. Changes will be incorporated in the engine to correct any deficiencies encountered at inspections and rebuilds. In this manner, design deficiencies which have not been uncovered or corrected during component development testing can be discovered and corrected early in the engine development program. Sufficient time is then available to incorporate and develop engine changes.

It is anticipated that a 250-hour endurance test will be completed on one engine set of parts by the time of FTS. By Engine Certification, it is anticipated that a 625-hour test will be completed on an engine with normal maintenance, periodic hot section inspections, and field cleaning as required.

b. Low Cycle Fatigue Testing

All gas turbine engine rotor disks are subject, in some degree, to cycle stresses as a result of changes in thrust level and, especially in the case of high Mach number engines, changes in inlet temperature. Past experience on commercial engines has shown that compressor disks, in particular, are life limited by low cycle fatigue. These cyclic stresses are due to the combined effect of centrifugal loading and thermally induced loading. The thermally induced loading is a function of the radial temperature pattern in the disk and is strongly influenced by the rate of change of engine inlet temperature. The cyclic life of the compressor and turbine disks is designed to be 12,000 cycles from SLTO to Mach 2.7 to SLTO or 20,000 cycles of idle to maximum nonduct-heat thrust to idle. Low Cycle Fatigue Testing is described in Section II of this report.

The low cycle fatigue life of a disk is a function of the radial temperature pattern, which is strongly influenced by the rate of change of inlet temperature. A realistic test program, therefore, must simulate the rate of change of inlet temperature, typical ascent and descent rates, and allow sufficient time for the disk temperatures to stabilize at the end points of the cycle. The SST Typical Mission Cycle test program, illustrated in figure 25, fulfills all their requirements. Therefore, the low cycle fatigue test program will be run in conjunction with the SST Typical Mission Cycle endurance program.

c. Thermal Fatigue Cyclic Testing

Thermal fatigue is a cyclic stress in turbine blades and vanes as a result of rapid changes in gas path temperature. The non-uniform response of the blade or vane (caused by variations in metal thickness in the case of uncooled parts and by variations in internal and external heat transfer coefficients in cooled parts), combined with centrifugal loading, causes a cyclic stress during thrust changes. The mass of the parts affected is considerably less than that of compressor or turbine disks. Therefore, the time required to reach a stabilized temperature is much less. The strongest influence on the stress level is rate of change of gas path temperature. Therefore, the thermal fatigue cycle was established on the basis of turbine inlet temperature change. The test program is illustrated in figure 26. Sea level takeoff condition was chosen rather than cruise condition since the turbine inlet temperature is higher and cooling air temperature is lower. This results in the highest stress levels.

Thermal fatigue testing will begin early in Phase III in a high spool engine, as described in the turbine section of the Component Development Plan, and will continue in the Phase III engine program. It is anticipated that confidence in the engine design, by demonstration of 500 cycles of Thermal Fatigue Testing, will be accomplished by FTS. A continuing program of thermal fatigue testing will be carried out throughout the engine development schedule. By Engine Certification it is anticipated that a demonstration test consisting of 1000 cycles will be completed.

6. Reliability and Safety Testing

The basic Safety and Reliability of the JTF17 engine will be developed through comprehensive testing. Although the major emphasis will be on full-scale engine testing, major component development testing will be employed to permit multiplication of experience on vital subassemblies beyond what will be obtained by full-scale engine testing. Components to be tested include the fan, compressor, primary combustor, duct heater, turbine, bearings, seals, accessory drive system, and all fuel and control system components. These subassemblies will be tested in a simulated service environment and also at overstress conditions.

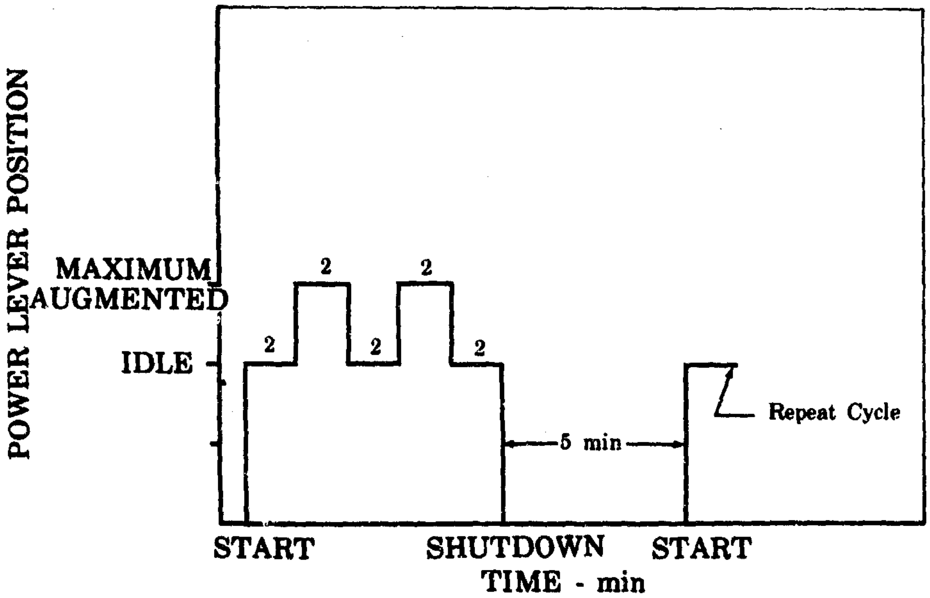

Figure 26. Thermal Fatigue Cycle FD 16793 EIII

The following full-scale tests will be performed during the development program:

1. Vibration testing of disks will be conducted in full-scale engine testing.

2. Oil tank structural tests will be conducted in accordance with FAR 25.1015 dated 1 February 1965.

3. Fuel system subassembly evaluation tests as described in the Component Test Section and Engine Test Section of this report.

4. Air bleed system subassembly evaluation tests as described in the Component Test Section. This system is also evaluated during the endurance testing described in the Engine Test Section of this report.

5. Electrical ignition proofing tests as described in the Component Test Section and the Engine Test Section, Control Systems Tests, of this report.

6. Structural load limit surveys including static frame tests in the laboratory simulating maneuver loads and vibration, and structural tests on full-scale engines as described in the Engine Test Section of this report.

7. Aerodynamic Brake Tests as described in the Engine Test Section, Windmill Testing, of this report.

8. Oil flow intersystem tests as described in the Engine Test Section, Lubrication System Tests, of this report.

9. Fuel contamination tests as described in the Engine Test Section, Airframe Fuel System Tests, of this report.

10. Engine-inlet compatibility testing as described in the Engine Test Section of this report and the Engine-Inlet Compatibility Test Program.

11. Anti-Icing Capabilities as described in the Engine Test Section, Anti-Icing Tests.

12. Vibration limits tests as described in the Engine Test Section, Vibration Test Program, of this report.

13. Engine durability tests as described in the Engine Test Section, Endurance Test Program, of this report.

14. Engine compartment temperature surveys will be taken during the testing described in the Engine Test Section, Lubrication System Tests, of this report.

15. Ice and bird ingestion tests as described in the Certification Test Section of this report.

16. Altitude thrust rating demonstrations as described in the FTS Program and Certification Test Sections of this report.

17. Jet wake temperature and velocity distribution will be determined during engine performance testing as described in the Engine Test Section of this report.

18. Engine generated noise level tests as described in the Engine Test Section, Noise Testing, of this report.

19. Demonstration of engine and augmentor relight capabilities at altitude as described in the Engine Test Section, Relight Tests, of this report.

20. Ambient inlet temperature starting and acceleration tests as described in the Engine Test Section, Starting Tests, of this report.

21. Flight test status test as described in the FTS Section of this report.

22. Engine Certification Test as described in the Certification Test Section of this report.

7. Maintainability Tests

During the normal development program of the JTF17 engine, maintainability features of the engine will be verified and improved. This program will be carried out during the assembly as well as the test phase of the development. The following items are typical of the maintainability documentation and improvement techniques to be used. A complete description of the Maintainability Plan is given in Volume IV, Report G, Section I.

1. Manhours required to remove and replace items such as the fuel control system components, major subassemblies of the engine (fan, low turbine, duct heater, etc.), and perform maintenance operations such as Hot Section Inspection (HSI) or Engine Heavy Maintenance (EHM).

2. Improvement of maintainability features by design changes and verification that the design intent has been attained.

3. Development of tools to improve maintainability, such as borescopes radioisotope inspection techniques, etc.

4. Vibration surveys to be conducted on the engine to determine the location of pickups and vibratory characteristics of the engine.

5. Sonic Analysis of the engine and verification of the changes in acoustical signature with failure modes.

6. Monitoring of engine parameters during engine testing to establish AIDS input in cooperation with the airframe manufacturer. A maintainability demonstration of the engine will be given in April 1968 to cover the following items:

    1. Periodic inspection - line maintenance
    2. Hot Section Inspection
    3. Engine maintenance (unitized assembly and disassembly).

8. Structural and Material Tests

Structural and material tests will be conducted during the development program of the JTF17 engine to verify that material selections meet the design requirements and that design goals are met in the structural design of the engine. These tests will be conducted in two general classifications:

a. Structural Tests of Engine Components

There are structural loads which are imposed on any aircraft engine, such as maneuver loads, which cannot be duplicated on a test stand. These loads are

simulated by structural frame testing in the laboratory with appropriate measurements of strain and deflection. A typical test setup is illustrated in figure 27. The results are then evaluated for conformance to the design goals. Corrections and retests are evolved as required until requirements are met.

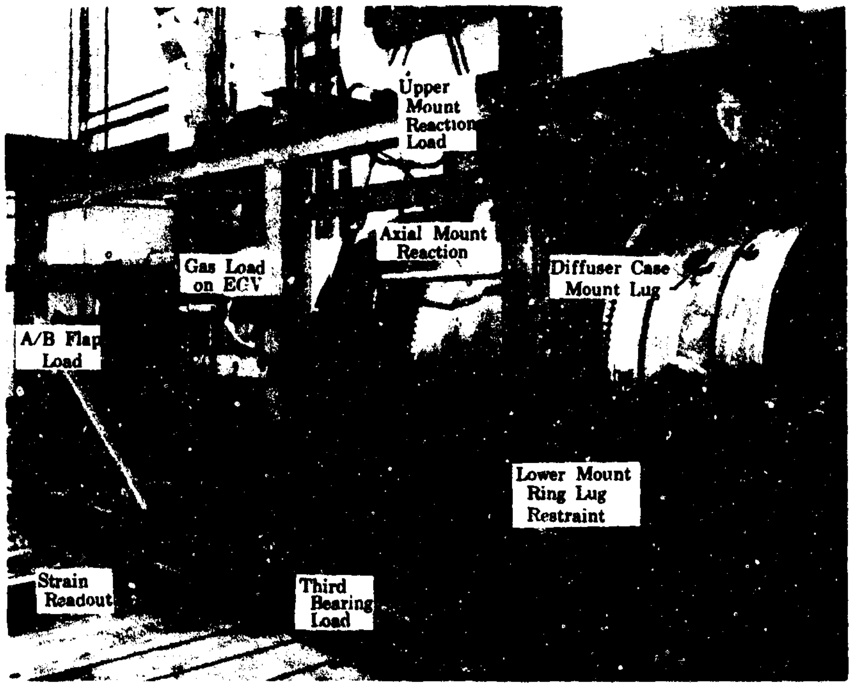

Figure 27. Static Frame Rig Test Setup (J58) FD 16811 EIII

b. Structural Engine Tests

Several parts of the JTF17 engine are designed to structural limits that occur at extreme points in the engine operating envelope. Other parts are designed at overspeed or overtemperature conditions for safety margins. Engine testing at these conditions will verify that these design goals have been met. This testing includes the following:

1. Engine testing at High Q conditions will be conducted during the development program.

2. Overtemperature tests as described in the FTS and Certification Section.

3. Low cycle fatigue testing as described in the Engine Test Section.

4. Thermal fatigue testing as described in the Engine Test Section.

5. Endurance testing as described in the Engine Test Section.

SECTION IV
FLIGHT TEST STATUS PROGRAM

A. INTRODUCTION

The Flight Test Status program will be conducted during the Phase III program to demonstrate that the JTF17 engine has the performance and durability suitable for continuation of the supersonic transport development program into the prototype flight test phase and the engine certification program of Phase IV. The FTS will consist of a series of engine tests, conducted as specified in Model Specification No. PWA 2698A and 2710. The tests will be conducted at operating and environmental conditions which simulate, insofar as possible, the most rigorous conditions anticipated during actual SST operation. Satisfactory completion of the FTS is required prior to delivery of the prototype JTF17 engines for flight test in conjunction with the SST airplane.

The proposed Flight Test Status program includes four major series of tests.

1. Performance Demonstration
2. Durability Demonstration
3. Reverser-Suppressor Durability Demonstrations
4. Supporting Durability and Reliability Demonstrations

These tests will be accomplished as part of the proposed Phase III program on development JTF17 engines and in test facilities provided for the Phase III program. The following are major milestones of the proposed JTF17 FTS program:

Date/Month After Phase III Go Ahead	Milestone
October, 1968	Start supporting durability and reliability tests
March, 1969	Assemble 1st FTS engine
March, 1969	Start sea level performance tests
May, 1969	Start sea level endurance tests
May, 1969	Start simulated altitude performance tests
June, 1969	Start simulated altitude endurance tests
May, 1969	Start reverser-suppressor feasibility test
June 30, 1969	Complete FTS

The following paragraphs describe in detail the proposed JTF17 engine FTS program.

B. FTS PERFORMANCE DEMONSTRATION

A development engine, assembled to the JTF17 prototype engine Parts List and instrumented to measure engine performance, will be used for the FTS Performance Demonstration. The reverser-suppressor will not be installed during the altitude testing. The Performance Demonstration will be conducted partially on a sea level test stand at FRDC and partially on an altitude-simulating test stand at FRDC. Approximately 50 hours of testing will be required to complete the test program.

The FTS Performance Demonstration will include:

1. Complete calibration of the engine at sea level static conditions between idle to sea level takeoff thrust.

2. Demonstration of all altitude guarantee points defined in Appendix A of the Engine Model Specification.

C. FTS DURABILITY DEMONSTRATION

A development JTF17 engine, assembled to the prototype engine Parts List except that the reverser-suppressor will be installed only during the sea level testing, will be used for the FTS Durability Demonstration. This test will be conducted partially on a sea level test stand at FRDC and partially on an altitude-simulating test stand at FRDC.

The engine will be operated for a total of 75 hours, exclusive of pre-endurance and post-endurance performance calibration tests. During the endurance tests, the engine will be operated in accordance with the schedules shown on figure 1. These schedules are representative of the operating and environmental conditions expected during actual service use of the engine in the SST. These proposed schedules are compared in table 1 with those accomplished as a part of the Flight Suitability Test conducted on the J58 engine.

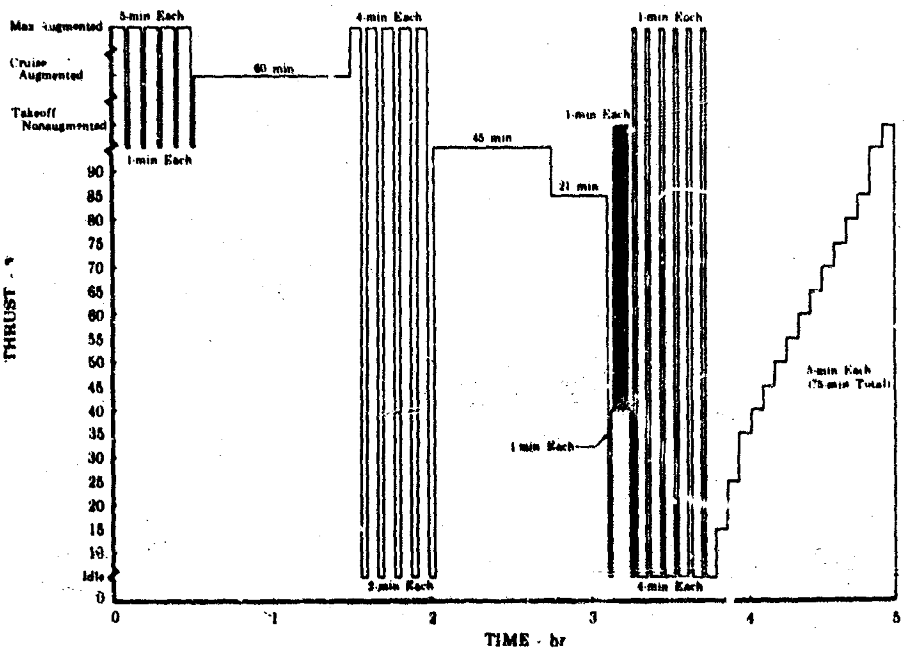

Figure 1. FTS Sea Level Endurance Cycle

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Table 1. Comparison of FTS Test Times (hours)

	JTF17	J58
Total Time	75	59.5
Sea Level Static	25	10.85
Simulated SST Flight	50	48.65
Hot Turbine Time	50.10	51.95
Sea Level Static	14.50	5.75
Simulated SST Flight	35.60	46.20
Augmented Time	44.77	48.53
Sea Level Static	9.17	2.33
Simulated SST Flight	35.60	46.20

The FTS Durability Demonstration will include:

1. Sea level engine performance calibration prior to endurance testing. This test will consist of a series of steady-state points from idle to maximum thrust in equal thrust increments.

2. Five sea-level-type endurance cycles of five hours duration each. Figure 1 shows the proposed sea level endurance cycle, which includes time at idle, nonaugmented and augmented conditions. At least three of these cycles shall be at the maximum specified fuel inlet pressure. At least two of these cycles shall be accomplished with 3% or more gas generator bleed flow. Total endurance time accumulated at these operating conditions, ~~and with~~ the reverser-suppressor installed and operating, is 25 hours.

3. Twelve simulated flight endurance cycles of four hours and 10 minutes duration each. Figure 2 shows the proposed altitude endurance cycle, which includes time at two cruise thrusts and idle. Total endurance time accumulated at these operating conditions, without the reverser-suppressor installed, is 50 hours.

4. Sea level engine performance calibration after completion of the endurance testing. This test will be the same as conducted on the pre-endurance calibration. The reverser-suppressor shall be re-installed for this calibration and the Final Acceptance Test. During the recalibration check run, the engine shall be adjusted to produce on a standard day, the nonaugmented thrust or maximum turbine discharge temperature, whichever is lower, that was obtained during the

initial calibration. During maximum augmented operation, duct heater fuel flow shall be adjusted so that, on a standard day, the total fuel flow will correspond to the flow that was obtained during the initial calibration.

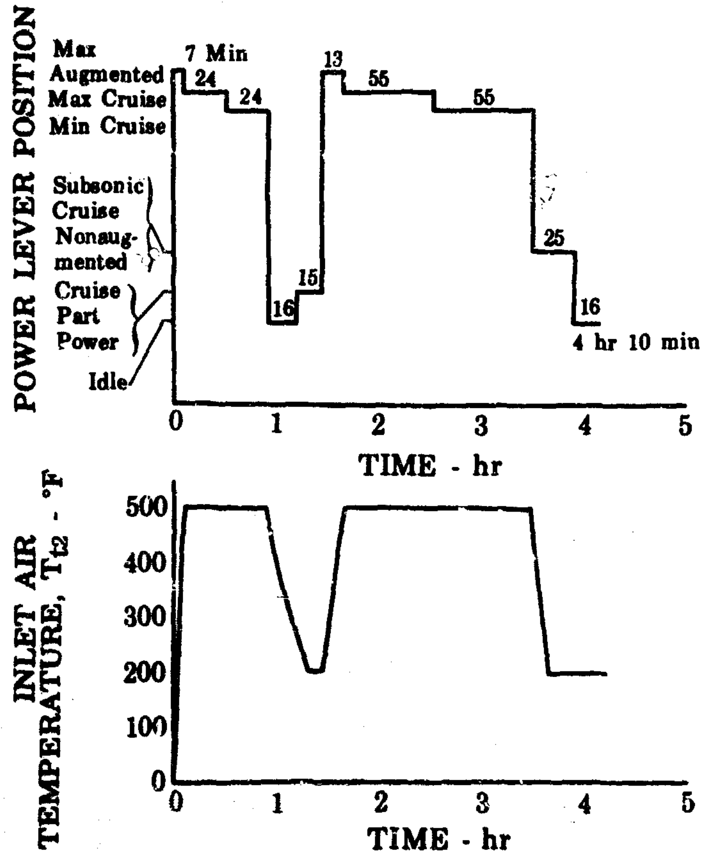

Figure 2. FTS Simulated Flight Cycle FD 17807
EIV

5. A final acceptance test, as specified in the current P&WA Production Acceptance Test Instruction Sheet f . the JTF17 engine, shall be run. During this run, the corrected jet thrust shall be not less than 95% of the initial calibration values, and the corrected specific fuel consumption shall not exceed 105% of the initial calibration values. The engine shall meet all other specified performance requirements which can be checked by the calibration procedure. This run may be preceded by a run-in period during which the cleaning procedure recommended for field use by the engine manufacturer may be applied. Satisfactory completion of this test shall be evidence of successful completion of the FTS.

D. REVERSER-SUPPRESSOR DURABILITY TESTS

The reverser-suppressor used for the sea level tests of the FTS Engine Durability Demonstration will be installed on another JTF17 engine(s), aerodynamically similar to the prototype JTF17 engine, and operated with this engine(s) until a total of 75 hours of reverser-suppressor test time, inclusive of that accumulated in the sea level testing conducted under item 2, above, shall have been accumulated. The test cycle is shown in figure 3. The reverser-suppressor will be reinstalled on the Durability Demonstration engine at the post-endurance calibration. Satisfactory completion of the Final Acceptance Test shall be evidence of successful completion of the FTS.

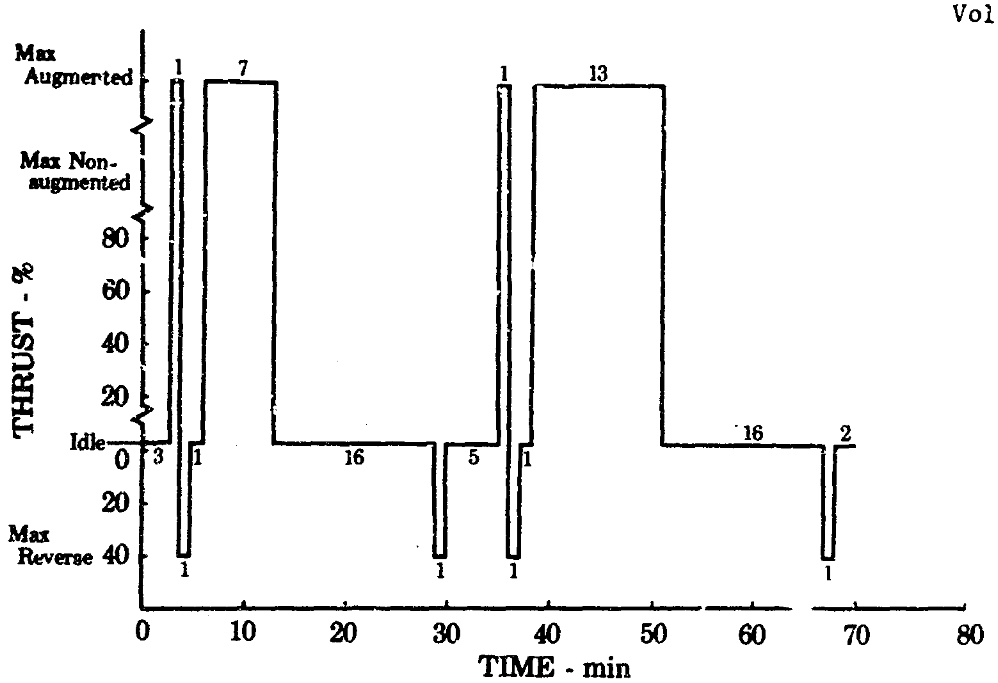

Figure 3. FTS Reverser-Suppressor Cycle FD 17806 EIV

E. SUPPORTING DURABILITY AND RELIABILITY TESTS

Although not a requirement for Flight Test Status, the following planned tests will be conducted on the JTF17 engine to ensure that the Flight Test program and the Phase IV Certification Test program will encounter a minimum of engine problems.

1. Preliminary endurance of a JTF17 development engine to the schedule of the FTS durability demonstration test

2. Preliminary calibration of a JTF17 development engine at the altitude guarantee points defined in Appendix A of the Engine Model Specification

3. Overspeed Test - In accordance with FAR 33.19, 33.27a, dated 1 February 1965, and AC20-26ch2, dated 8 July 1965, representative JTF17 fan, compressor and turbine disks with dummy blades installed will be spun in a spin pit to 120% of their maximum normal operating speed. The disks will be subjected to their maximum operating temperature conditions during the spin tests.

4. Containment Tests - During the course of engine development testing, including tests at overspeed, overtemperature, and high vibratory and stress levels, some failures of engine parts will undoubtedly occur. The ability of the engine to contain these failures will be demonstrated by these tests. In addition, failures which may occur in fan, compressor and turbine test rigs will also serve to demonstrate the ability of the engine design to contain failures. It is to be noted that the test rigs utilize engine-type cases or the equivalent.

5. Low Cycle Fatigue Testing - Verification of the low cycle fatigue life of the compressor disks will be demonstrated prior to FTS as described in Section III of the Engine Test Plan. It is anticipated that 250 cycles

of low cycle fatigue endurance will be completed by the end of Phase III. A cycle consists of consecutive takeoff, climb, cruise, and descent conditions.

6. Thermal Fatigue Testing - Verification of the thermal fatigue life of the critical first stage (highest gas temperature) turbine blades and vanes will be demonstrated in the High Spool Rig as described in Section II of the Component Test Plan.

7. Aerodynamic Brake Testing - In accordance with the proposed FAR 33.98, dated 1 November 1965, the aerodynamic brake will be subjected to 25 cycles from normal engine operating position to shutdown and back to operating position on development JTF17 engines, assembled substantially to the prototype parts list, operating at the expected maximum windmilling engine speed. This test will be conducted at simulated cruise environmental conditions.

SECTION V
FLIGHT TEST PROGRAM

A. INTRODUCTION

The operational suitability of the SST engine-airframe combination functioning as a system will be determined, in a large part, by the 100-hour Flight Test Program to be initiated in Phase III. Pratt & Whitney Aircraft will work closely with the airframe manufacturer to conduct a flight test program directed toward successful demonstration of the capability of the SST to accomplish the basic domestic and international missions. The major test programs and their time-phasing are illustrated in figure 1.

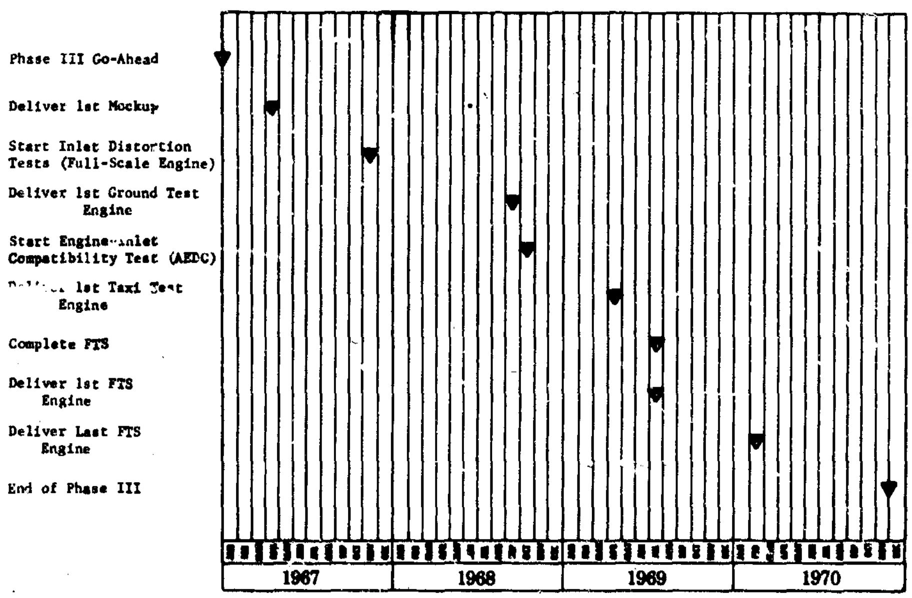

Figure 1. Flight Test Program

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EV

B. FLIGHT TEST PROGRAM OBJECTIVES

The prime objective of the flight test program is to develop and demonstrate the operational suitability of the SST engine-airframe combination. The following Phase III Program objectives are directed toward this goal.

1. Prepare, implement and maintain a Flight Test Program in conjunction with the airframe contractor.
2. Demonstrate suitability of the prototype JTF17 engine for flight test by successful completion of the FTS.
3. Deliver the twenty Ground, Taxi, and Prototype JTF17 engines.
4. Provide adequate engineering and product support coverage at all test sites during all phases of the flight test program.

C. PHASE II-C STATUS

During Phase II-C, the following activities related to engine-inlet compatibility have been achieved. A complete description of these activities is contained in Volume III, Report D, Section II, Engine-Inlet System Compatibility.

1. Analog and/or digital simulations of the engine, inlet, and their associated control systems have been exchanged, and updated as required, between Pratt & Whitney Aircraft and the airframe contractors.

2. Inlet distortion data for a variety of flight conditions have been received from the airframe contractors. These data, obtained from model tests, have been reviewed with respect to distortion tolerance of the JTF17 engine and associated performance effects.

3. An engine-inlet compatibility test program, to be conducted at AEDC, has been coordinated with both candidate airframe contractors.

4. The development of a computer program to predict the effects of transient distortion on fan and compressor performance and surge margin has been started.

D. PROPOSED PROGRAM IN SUPPORT OF FLIGHT TEST PROGRAM

1. Introduction

The prototype JTF17 engines supplied by Pratt & Whitney Aircraft for the 100-hour Flight Test Program will represent the product of approximately 10?,?00 hours of component test time and approximately 4000 hours of full-scale engine testing as described in prior sections of this report. They will be of proven performance and operational suitability. To ensure this goal and to ensure, insofar as possible, that a successful Flight Test Program will be accomplished, the following test program will be conducted. Where applicable, the program is coordinated with the airframe contractor and a constant interchange of data is maintained.

2. Supporting Tests

The JTF17 engine development program to be conducted at Pratt & Whitney Aircraft during Phase III will be directed toward the delivery of highly developed JTF17 engines for the flight test program. Data obtained from the flight test program and continued development engine testing will provide the basis for any corrective action required on the engine. The engine changes that are involved will be endurance tested and retrofit parts quickly supplied throughout the 100-hour Flight Test Program. Thus, the test programs listed below are common to the engine development cycle prior to delivery of the engines and to the corrective action cycle for problems encountered in the Flight Test Program.

a. Rig Distortion Testing (P&WA)

Steady-state and transient air inlet profile distortion tolerance testing of the JTF17 fan will be conducted beginning early in Phase III. Distortion patterns received from the airframe manufacturer will be simulated by placing screens in front of the fan inlet. Data from this testing will be evaluated for adequacy

of surge margin and other effects on performance parameters. Corrective action, as required, will be taken until the desired goals are obtained. This test program is more completely described in Volume III, Report E, Section II.

b. Full-Scale Engine Distortion Testing (P&WA)

Full-scale engine inlet profile distortion testing will be conducted throughout Phase III. This testing will be conducted in two phases. Initial testing will be conducted simulating distortion levels by installing distortion screens or a distortion generator in front of the engine inlet. As soon as sufficient definition of the airframe inlet and its performance is received, a simulated inlet will be installed on the engine for distortion testing.

The t sting will include steady-state and transient engine operation at a variety of simulated flight conditions representative of the SST operational conditions. Data from these tests will be evaluated for the effect on overall engine performance and durability as well as effects on individual engine components. This testing is described in detail in Report E, Section III.

c. Engine-Inlet Compatibility Test (AEDC)

A full-scale engine-inlet compatibility test program has been coordinated with the airframe contractors and will be conducted at AEDC during Phase III. This test provides the maximum duplication of factors influencing engine-inlet compatibility, with the exception of actual flight. This program is described in detail in Volume III, Report D, Section II.

d. Airframe Component-Engine Compatibility Tests at P&WA

The compatibility of the engine and airframe components such as engine-driven airframe accessories will be demonstrated by engine testing during the Phase III program at P&WA. These tests will be conducted during the engine development program to a mutually agreed upon program and schedule. The scope of the test program will depend on the nature of the component to be tested. It is, however, planned that airframe components will be installed on experimental JTF17 development engines as soon as they become available.

3. Engine Delivery Schedule

The engine delivery schedule for Ground, Taxi and Flight Test Program is shown in figure 2. It is to be noted that the prototype engines delivered in May of 1969 are taxi test engines, which will be refurbished to the FTS configuration at Pratt & Whitney Aircraft.

4. Instrumentation and Calibration

Since these engines will provide the data for verification of the engine-airframe compatibility and suitability, they must be calibrated and instrumented. A proposed schedule of instrumented and calibrated engines is included in figure 2. Engines which are designated as Instrumented Engines will incorporate the items shown in figure 3 and will incorporate additional instrumentation provisions in the form of "kit" parts which can be supplied with the engine.

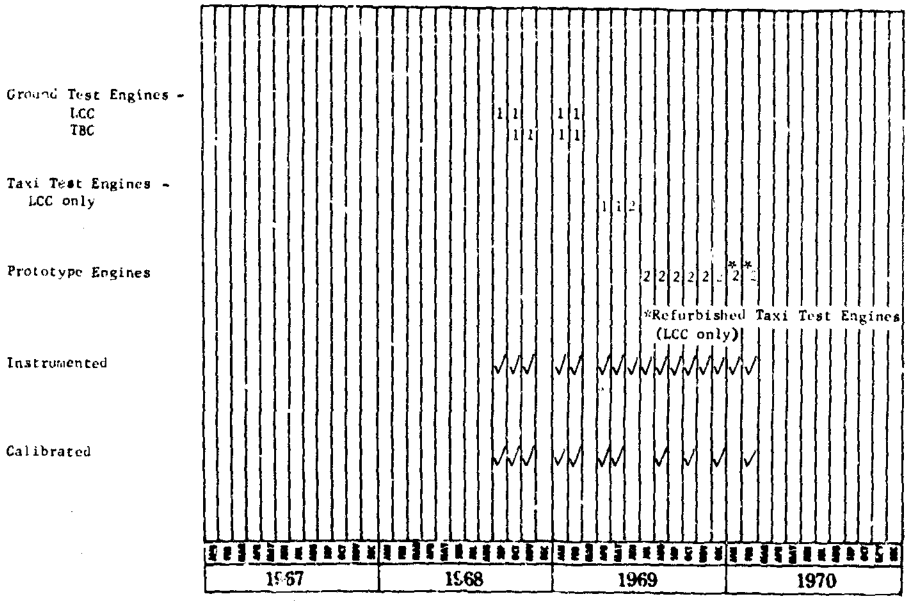

Figure 2. Engine Delivery Schedule, Ground, Taxi, and Flight Test Program FD 16798 EV

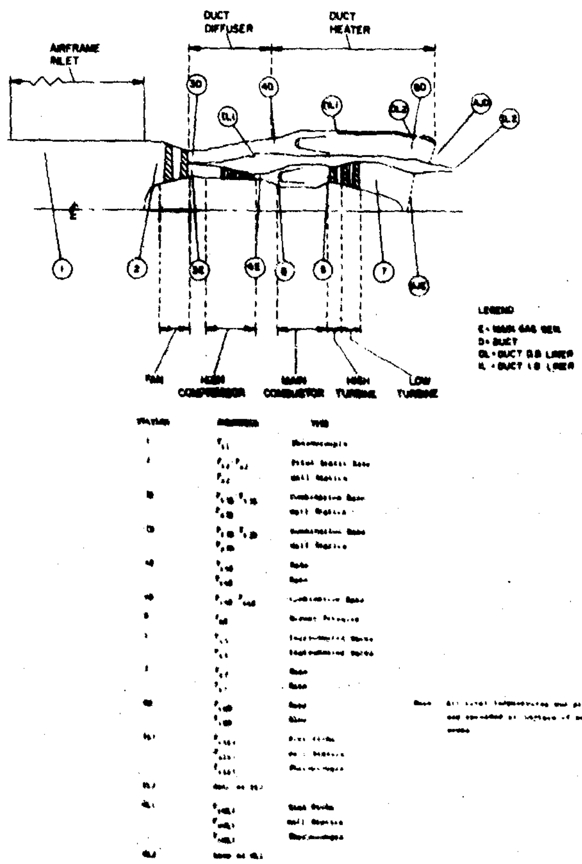

Figure 3. JTF17 Engine Instrumentation FD 16799 EV

Engines which are designated Calibrated Engines will undergo a calibration test at Pratt & Whitney Aircraft prior to delivery. This test will consist of a series of steady-state points from idle to maximum augmented thrust in approximately equal thrust increments. The details of the calibration program will be mutually agreed upon by Pratt & Whitney Aircraft and the airframe contractor. Test data will be supplied to the airframe contractor.

5. Ground Test Program

The proposed ground test program is a coordinated effort with the airframe contractor and will include the programs outlined in the following paragraphs. In all cases, the detail programs will be mutually agreed upon by Pratt & Whitney Aircraft and the airframe contractor.

a. Uninstalled Cround Test

This test will consist of engine and noise tests to be conducted in a ground test facility supplied by the airframe contractor. The purpose of the test is to verify the compatibility of the engine with the inlet and airframe assessories as well as provide engine-inlet performance data. An instrumented and calibrated engine will be used in this test program.

b. Installed Ground Test Program

This will consist of engine tests to be conducted in an airframe at static conditions. The purpose of the test is to verify engine-airframe compatibility. The test program will include the following areas of interest.

(1) Starting

The starting characteristics of the installed engine will be demonstrated and the effects of the inlet on the engine, the adequacy of the starter system, and verification of the starting fuel shcedules will be determined. Pertinent parameters such as starter torque, fuel flow, ignition timing and rotor speeds will be recorded at both transient and steady-state conditions.

(2) Thrust Response

The forward and reverse thrust response of the engine will be demonstrated by rapid movement of the power lever from idle to maximum augmented position for forward thrust and from idle to reverse position for reverse thrust. Transient recordings of pertinent engine parameters, thrust, fuel flow and rotor speeds, duct heater nozzle position, and gas generator exit temperature and pressure will be made. Thrust will be calculated from engine parameters.

(3) Installed Performance

The installed performance of the engine will be determined by a test onsisting of a series of steady-state points from idle to maximum augmented thrust and from idle to maximum reverse thrust. Points will be taken at approximately equal thrust increments. All engine performance parameters will be recorded. Thrust will be calculated from the measured engine parameters.

(4) Vibratory Characteristics

The vibratory characteristics of the engine-airplane combination will be demonstrated by recording data from vibration pick-ups mounted on the engine and airframe at pertinent locations. These locations will include engine inlet, engine intermediate case, engine rear mount case, engine gearbox, airframe inlet, airframe accessories and the like. Steady-state data will be obtained during the Installed Performance tests; transient data will be obtained during the Thrust Response Tests.

(5) Reverser Tests

In addition to reverse thrust response and reverse thrust level measurements, the compatibility of the engine and airframe for reverse thrust targeting and flow area will be verified by ground tests.

(6) Noise Testing

Near and far field noise measurements of the installed engine will be made at various power levels representative of approach, taxi, and takeoff conditions.

(7) Inlet Distortion

During the Installed Performance tests, inlet profile distortion data will be obtained at steady-state conditions; similar data under transient conditions will be obtained during the Thrust Response tests.

(8) Nacelle Environment

The compatibility of the engine and nacelle combination will be verified by recording of nacelle and engine skin temperatures, secondary airflow (including pressure and temperature) and the like during the ground test programs previously described.

(9) Maintainability Demonstration

During the entire Flight Test Program, the maintainability of the installed engine will be developed and demonstrated while performing routine servicing of the engine and its components and by component replacement as required during the test program.

c. Taxi Tests

(1) Reverse Thrust

The reverse thrust response and adequacy of reverse thrust level will be verified by a test consisting of actuating the thrust reverser at various taxi speeds. The speeds will be chosen to simulate typical landing rolls and aborted takeoff The gross weight of the airframe will be typical of the SST for these conditions. The effect of reingestion of reverse thrust gases will be evaluated during these tests

(2) Foreign Object Ingestion

The susceptibility of the engine-airframe combination to ingestion of foreign objects during takeoff and landing rolls will be determined by a test consisting of taxing the airframe at various speeds including taxi, takeoff, landing and reverse thrust conditions. This test is a coordinated effort with the airframe contractor.

d. Flight Tests

Flight testing of the engine will accomplish the task of evaluating engine-airframe performance and reliability characteristics which are beyond the capabilities of ground test facilities. Instrumentation requirements for steady-state and transient tests are given in tables 1 and 2, respectively. The flight test program for the SST will be coordinated with the airframe contractor and will include the following tests:

Table 1. Steady-State Instrumentation List

Low Rotor Speed

High Rotor Speed

Compressor Inlet Temperature and Pressure

Fan Discharge Temperature and Pressure - Duct Side
- Engine Side

High Compressor Discharge Temperature and Pressure

Main Burner Pressure

Turbine Inlet Temperature and Pressure

Turbine Discharge Pressure and Temperature

Duct Heater Inlet Pressure and Temperature

Duct Heater Discharge Temperature and Pressure

Duct Heater Nozzle Position

Fuel Inlet Pressure and Temperature

Main Fuel Pump Discharge Pressure

Hydraulic Pump Discharge Pressure

Duct Pump Discharge Pressure

Total Fuel Flow

Main Engine Fuel Flow

Duct Heater Fuel Flow

Duct Fuel Control Burner Pressure

Power Lever Position

Reverser-Suppressor Position - Clamshells
- Blow-in-door
- Tailfeather

Table 1. Steady-State Instrumentation List (Continued)

Compressor Interstage Bleed Position

Main Oil Pressure

Main Oil Temperature

Breather Pressure

Fuel-Oil Cooler (Main and Duct Heater) - Oil in Temperature
- Oil out Temperature
- Fuel in Temperature
- Fuel out Temperature

Aerodynamic Brake Position

Table 2. Transient Instrumentation List

Low Rotor Speed

High Rotor Speed

Fan Discharge Pressure and Temperature - Duct Side
- Engine Side

High Compressor Discharge Pressure and Temperature

Main Burner Pressure

Turbine Discharge Pressure and Temperature

Duct Heater Nozzle Position

Total Fuel Flow

Main Engine Fuel Flow

Power Lever Position

Compressor Interstage Bleed Position

Aerodynamic Brake Position

(1) Performance

Performance of the engine will be determined at various flight conditions. These conditions will include subsonic, transonic and cruise conditions. Steady-state points will be taken at these flight conditions at various altitudes which are representative of the SST. Data to be recorded include rotor speeds, duct heater nozzle position, fuel flow, engine inlet pressure, engine inlet temperature, gas generator exit temperature and pressure.

These data will be evaluated to ensure conformance to specification engine performance requirements as well as to ensure adequate surge margins for the fan and high compressor. The effects of accessory horsepower extraction and air bleed on engine-airframe performance will also be evaluated during these tests.

(2) Windmill Tests

Windmill performance of the engine with the aerodynamic brake on and off will be determined at representative SST flight speeds including subsonic, transonic and cruise conditions. Data from this program will be analyzed to determine windmill drag and oil system heat rejection. Special instrumentation required for heat rejection data is shown in table 3. A portion of this data may be obtained during the flight relight programs.

Table 3. Heat Rejection Instrumentation

Main Oil Pressure

Main Oil Temperature

Breather Pressure

No. 1 - 2 bearing compartment - oil in flow
- oil in pressure
- oil in temperature
- oil out temperature

No. 3 bearing compartment - oil in flow
- oil in pressure
- oil in temperature
- oil out temperature

No. 4 bearing compartment - oil in flow
- oil in pressure
- oil in temperature
- oil out temperature

Fuel in temperature at main and duct heater pump

Main fuel-oil cooler - oil in temperature
- oil out temperature
- fuel in temperature
- fuel out temperature

Duct Heater fuel-oil cooler - oil in temperature
- oil out temperature
- fuel in temperature
- fuel out temperature

Total fuel flow

Main engine fuel flow

Duct heater fuel flow

Low rotor speed

High rotor speed

(3) Vibratory Characteristics

The vibratory characteristics of the engine will be verified by recording data from vibration meters installed at the engine inlet case, the intermediate case, rear mount case and gearbox. This data will be taken in conjunction with the other flight test programs.

(4) Inlet Profiles Distortion Testing

The inlet distortion level of the engine-inlet system will be determined by recording pressures at the engine inlet. Pressure probes will be located to determine both radial and circumferential profiles. Data will be recorded during subsonic, transonic and cruise flight conditions. The effect of an inlet unstart on the engine inlet profile will be determined during this testing. Data will be evaluated for conformance to the distortion levels specified in the Engine Model Specification as well as its effect on engine components, such as fan and compressor surge margin, turbine inlet temperature profile and duct heater inlet conditions.

(5) Relight Tests

Relight tests of the engine, both main combustor and duct heater, will be conducted to verify the in-flight relight capabilities of the engine. The effect of relights on the engine-inlet combination will be determined as well as verification of the relight envelopes defined during the engine development program.

(6) Nacelle Environment

Verification of the compatibility of the engine-nacelle combination will be obtained during the flight test program by data obtained from instrumentation such as nacelle skin temperatures, engine case temperatures, secondary airflow quantity, temperature, etc. This program may be run in conjunction with other programs such as the performance testing.

(7) Oil System Tests

The suitability of the engine oil system at flight conditions will be verified by data obtained during the other flight test programs. These data will include heat rejection rates, oil consumption rates, engine breather pressure and flow, main oil pump performance and scavenge system performance.

(8) Control System Tests

Verification of fuel control schedules and the effects of environmental conditions on these schedules will be obtained at the following conditions. Instrumentation requirements for steady-state and transient operation is given in tables 4 and 5, respectively.

Table 4. Steady-State Instrumentation List Control System

This instrumentation will be required but not simultaneously:

- High Rotor Speed
- Low Rotor Speed
- Fuel Inlet Pressure
- Fuel Inlet Temperature
- Main Pump Discharge Pressure
- Hydraulic Pump Discharge Pressure

Table 4. Steady-State Instrumentation List
Control System (Continued)

Duct Pump Discharge Pressure

Main Engine Fuel Flow and Temperature

Duct Heater Fuel Flow and Temperature

Tank Return Fuel Flow and Temperature

Main Fuel Control Burner Pressure

Duct Control Burner Pressure

Power Lever Position

Exhaust Nozzle Position

Reverser-Suppressor Position

Compressor Bleed Pilot Valve Position

Control Ambient and Skin Temperature

Duct Pump Ambient and Skin Temperature

Ignition Exciter Ambient and Skin Temperature

Control Ambient Air Velocity

Duct Pump Ambient Air Velocity

Ignition Exciter Ambient Air Velocity

Vibration Pick-ups on Unitized Fuel Control, Hydraulic Pump and both Ignition Units

Mach Number

Altitude

KEAS

Inlet Bypass Door Position

Inlet Shock Position

Engine Thrust

Table 5. Transient Instrumentation List

The following items are required for occasional transient recordings for the fuel control system:

Exhaust Nozzle Open Pressure

Exhaust Nozzle Closed Pressure

Inlet Guide Vane Increase Pressure

Inlet Guide Vane Decrease Pressure

Remote Main Engine Fuel Trim Operation

Table 5. Transient Instrumentation List (Continued)

Main Control Discharge Pressure

Zone 1 Manifold Pressure

Zone 2 Manifold Pressure

Remote Duct Fuel Trim Operation

Remote P/P Trim Operation

Duct Heater Ignition Indicator

Gas Generator Ignition Indicator

Accelerometers on Aircraft Suitable to Measure Effects of Various Thrust Discontinuities, i.e., Duct Heater Lights

(a) Steady-State

1. Typical climb path with representative power lever settings.
2. The effect of long time operation at elevated temperatures on the fuel control schedules.
3. Typical descent path with representative power lever settings.
4. Typical go-around
5. Extremes of aircraft flight envelope
6. Soak at various flight path conditions, during climb, cruise and descent, to obtain steady-state data on control and inlet operation and heat rejection data
7. Typical aircraft maneuvers at various flight path conditions, including cruise.

(b) Transient Operation

1. Engine acceleration and deceleration characteristics at various operating conditions, includes maximum augmentation, maximum nonaugmentation, idle and reverse; as applicable, at various flight path conditions including climb, cruise, descent and during typical aircraft maneuvers.
2. Control and Inlet Operation malfunctions and failure simulation will be investigated. Among those to be evaluated are the following:

   a. Inlet unstart
   b. Unstable Inlet
   c. Inlet Discharge Profile Distortion
   d. No light of duct heater
   e. Aerodynamic brake actuation

f. Duct heater and gas generator blow outs

g. Short time loss of fuel inlet pressure, during both augmented and nonaugmented operation.

h. PLA and cut off lever failure (if electrical)

(c) Ignition System Operation

1. Duct heater lights at various conditions in climb, cruise, and descent path, and at extremes of aircraft flight envelope

2. Gas generator relights at various conditions in climb, cruise, and descent path, and at extremes of aircraft flight envelope.

E. DATA FLOW

The data obtained from the Flight Test Program will be evaluated by Pratt & Whitney Aircraft in cooperation with the airframe contractor. Data flow and procedures will be coordinated with the airframe contractor during Phase III.

F. PRODUCT SUPPORT

Pratt & Whitney Aircraft will provide qualified Engineering, Field Service and Technical personnel at field activities in ample time to ensure coordination with the airframe manufacturer and completion of plans and facilities prior to ground and flight test operations. Experienced Field Engineers and Field Service Representatives are presently located at the Boeing and Lockheed plants and will continue to provide direct contact during the ground, flight test and production programs. These men will assist the manufacturer by supplying engine performance data, product support and maintainability information. The Product Support functions are as follows:

1. Ground Test - Engines will be delivered for ground test programs at AEDC, Tullahoma and at the airframe manufacturer's test facility. Field Engineers and Field Service Representatives will be assigned specifically to each activity to assist the manufacturer's engineering test and maintenance personnel on the operation, performance and maintenance of the engine. These men will supplement the Service School training and Handbooks available to the airframe contractor's personnel by conducting continuing on-the-job training programs to ensure that the tests include the latest engine procedures, techniques and limits.

2. Flight Test - The Pratt & Whitney Aircraft SST Product Support Organization will provide Field Service Representatives, Field Engineers, Spare Parts Representatives, Technicians, GSE and spare parts required for maintenance and operation of the JTF17 Engine throughout the flight test program.

A more detailed description of the Product Support Plan is given in Volume IV, Report C, Section VI.

SECTION VI
CERTIFICATION TEST PROGRAM

A. INTRODUCTION

Assuming a 30 September 1966 go-ahead for long lead time Phase III hardware, and an uninterrupted continuation of the engine development program with timely and adequate funding, the JTF17 Engine Certification Test should be completed in December 1971. It is anticipated that 14,500 hours of full-scale JTF17 engine testing will be accomplished prior to conduct of the Certification Test, including 5800 hours of testing at simulated SST flight conditions. The Phase IV development program leading to engine certification is a continuation of the Phase III program with changes being incorporated in the Parts List established for the JTF17 engine to upgrade the performance, reliability, and durability of the engine. These changes will be evolved from a continued development program, involving both component and full-scale engine testing, and from the results of the Flight Test Program.

Following type certification of the engine, a vigorous and comprehensive program will be conducted in support of the airframe certification test program. It is anticipated that 27,500 hours of engine test time will be accumulated, including 11,000 hours of simulated altitude-Mach number time, by airframe certification. As the SST is put into commercial service, a sustaining engineering development program directed at the solution of service problems and growth of the engine must be continued. The potential growth of the engine is described in Volume III, Report G.

The Engine Certification Test will be conducted in accordance with the applicable parts of FAR-25, dated 1 February 1965; FAR-33, dated 1 February 1965; the proposed FAR-33 for SST engines dated 1 February 1966, Advisory Circulars 33-1 dated 24 June 1965; 20-26, dated 8 July 1965; and 20-18A dated 16 March 1966; and the Engine Model Specifications, PWA 2698A and 2710. Table 1 is a compilation of the Certification requirements and the appropriate Federal Aviation Regulation and Advisory Circulars.

The JTF17 production engine will be produced at the East Hartford Division of Pratt & Whitney Aircraft. Therefore, the substantiating data for certification of the engine will be submitted to the Federal Aviation Agency Eastern Regional Headquarters.

Table 1. Certification Requirements

Test	FAR	AC
Suitability and durability of materials	33.15	
Durability		
Blade containment	33.19	33-1
Fan and compressor overspeed	33.19	20-26
Rotor integrity (design margins)	33.19	
Mounting attachments		
Overspeed	33.27a	20-26
Overtemperature	33.27A	20-26
Disk and blade stress	33.27b	20-26

Table 1. Certification Requirements (Continued)

Test	FAR	AC
Vibration	33.83	
Anti-icing inlet system	33.67a and b	
Lubrication system	33.71	
Foreign object ingestion	33.12	33-1
Surge characteristics	33.65	
Thrust response	33.73	
Calibration	33.85	
Endurance	33.87	
Starts	33.87b6	
Maximum oil temperature	33.87b7	
Maximum exhaust temperature	33.87b7	
Maximum rotor speed	33.87A	
Gearbox substantiation	33.91a	
Component - substantiation	33.87	
Component - environmental temperature	33.91b	
Thrust reverser	33.97a and b	20-18A
Oil tank	25.1015	
	PROPOSED FAR	
Turbine rotor cooling	33.27	
Safety standards		
Failure detection of cooling schemes	33.75	
Malfunction of automatic devices	33.75	
Maloperation of shutdown devices	33.75	
Single failures and combined failures	33.75	
Foreign object ingestion		
Preclude extreme hazards	33.77	
Minimize potential severe hazards	33.77	
Aerodynamic brake	33.98	

The anticipated time schedule for the certification plan is as follows:

Item	Date
Build 1st certification test engine	February 1971
Start Reliability and Durability Tests	March 1971
Start sea level performance test	August 1971
Start simulated altitude performance test	August 1971
Start sea level endurance test	November 1971
Start simulated altitude endurance test	November 1971
Complete engine certification tests	31 December 1971

The following tests, described in the referenced paragraphs of this section, will provide the substantiating data to be submitted to the Federal Aviation Agency for Certification of the JTF17 engine:

Test	Reference Paragraph	FAR	AC
Endurance - Engine	B	33.87	
Endurance - Reverser-Suppressor	B	33.97 a and b	20-18A
Performance Demonstration	C	33.85	
Mission Cycle Test	D	33.15	
Low Cycle Fatigue Test	E	33.15	
Thermal Fatigue Test	F	33.15	
Low and High Maximum Rotor Speed	G	33.87a	
Maximum Exhaust Gas Temperature Test	H	33.87b	
Overtemperature Test	I	33.27a	20-26
Aerodynamic Brake Test	J	33.98	
Foreign Object Ingestion Test	K	33.13	33-1
Engine Inlet Icing Test	L	33.67 a and b	
Overspeed Test	M	33.27a	20-26
Gearbox Test	N	33.91a	
Fan, Compressor and Turbine Rotor Stress Demonstration	O	33.27b	20-26
Blade Containment	P	33.19	33-1
Oil Tank Test	Q	25.1015	
Component Substantiation	R	33.87	
Turbine Rotor Cooling	S	33.27	
Contamination Test	T	33.27	
Engine Systems Failure Analysis	U	33.75	
Control System Failure Analysis	V	33.75	

B. ENDURANCE TEST

1. General

A JTF17 engine assembled to the production Parts List will be utilized in this test. Certification testing of the engine and reverser-suppressor will be conducted with inlet distortion representative of the SST and as defined in the Engine Model Specification. The level of distortion will be coordinated with the FAA and the airframe contractor. The test shall be conducted in accordance with FAR 33, dated 1 February 1965.

2. Proposed Certification Te ·s

The engine endurance testing shall be conducted to a schedule acceptable to the FAA. The following paragraphs describe an SST-oriented mission cycle engine endurance test for consideration. The cycle selected is shown in figures 1 and 2. This test was constructed by considering typical international missions as obtained from the airframe contractors. The first climb-cruise-descent, Part A of figure 2, represents an "average" 1980-statute-mile mission defined by the FAA Economic Ground Rules, dated 30 June 1966. The second climb-cruise-descent, Part B of figure 2, coupled with the sea level cycles represents the 4000-statute-mile mission. The 30 simulated altitude cycles in a 150-hour test represent 60 missions of the SST. Thus, the sea level cycle, figure 1, was chosen to represent the takeoff and subsonic portions of the 60 missions. The total endurance time accumulated on the engine shall be 150 hours.

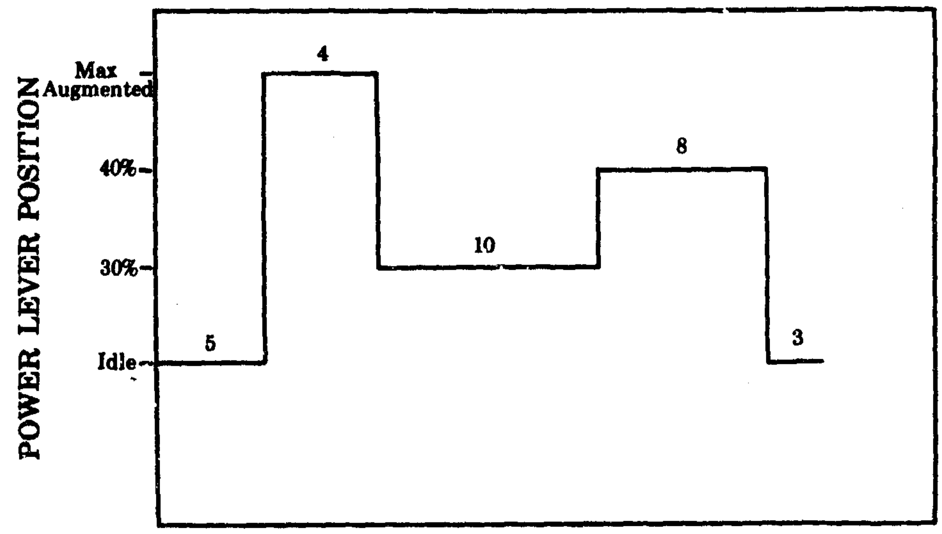

Figure 1. Proposed Sea Level Cycle

FD 16803
EVI

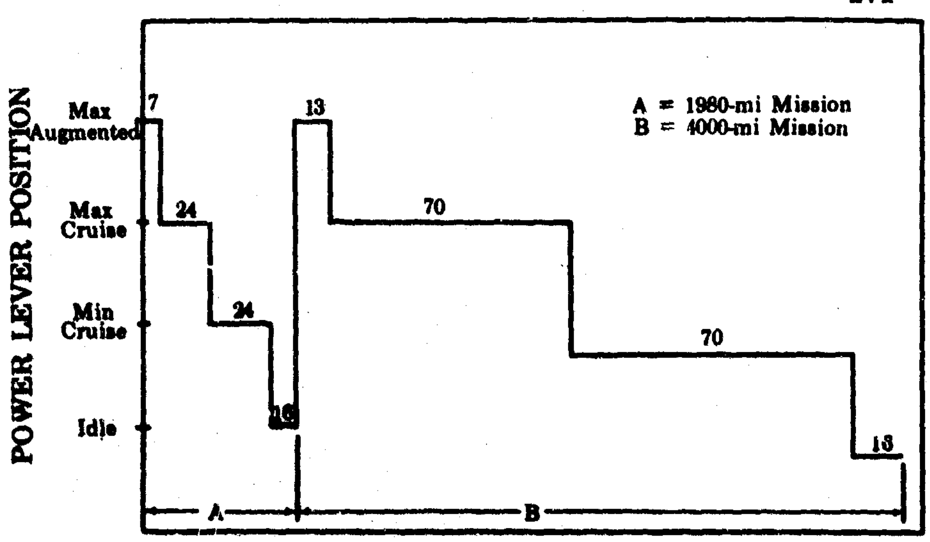

Figure 2. Proposed Altitude Cycle

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EVI

a. Calibration

A pre-endurance calibration with full instrumentation will be conducted from idle to sea level takeoff power. This calibration will establish the engine operating conditions for the endurance test. All gas path instrumentation except inlet and exhaust gas temperature and pressure probes will be removed for endurance.

b. Adjustments

Prior to endurance, the control system will be adjusted to obtain takeoff thrust with the power lever in the takeoff thrust position. During the test, control system adjustments shall be made as required to maintain the rated thrust.

c. Sea Level Static Endurance

The sea level endurance portion of the 150-hour test will consist of 60 cycles of 30 minutes duration each, for a total of 30 hours. The reverser-suppressor will be installed for this portion of the Certification Test. The cycle is shown in figure 1. The time is distributed as follows:

Engine Power Setting	Simulated Environmental Condition	Hours	% of 150 Hours
Takeoff, Fully Augmented	Takeoff	4	2.6
40% TO, Nonaugmented	Approach	8	5.3
30% TO, Nonaugmented	Hold	10	6.7
Idle	-	8	5.4

d. Simulated Flight Endurance

The simulated flight endurance test consists of 30 cycles of 4 hours duration each, simulating climb, cruise and descent conditions, for a total of 120 hours. This portion of the endurance test will be conducted without the reverser-suppressor installed. The time is distributed as follows:

Engine Power Setting	Simulated Flight Condition	Compressor Inlet Temperature, °F	Fuel Inlet Temp, °F	Hours	% of 150 Hours
Maximum, fully augmented	Climb	200 to 495	210	10	6.7
Maximum Cruise	Cruise	495	-	47	31.35
Minimum Cruise	Cruise	495	-	47	31.35
Idle	Descent	495 to 200	-	16	10.6

The engine test cycle is shown in figure 2.

e. Starts

A minimum of one hundred starts will be accomplished. Twenty-five of these must be preceded by at least a 2-hour shutdown. Ten false starts, followed by the minimum fuel drainage time and a normal start, will be conducted. For the starts which are not performed in the pre- and post-endurance calibration, adjustments or endurance will be made after completion of the endurance test.

f. Post-Endurance Calibration

A post-endurance calibration will be conducted on a sea level test stand. The reverser-suppressor will be installed for this and the final acceptance test. During the calibration, the engine shall be adjusted to produce, on a standard day, the nonaugmented thrust or maximum turbine discharge temperature, whichever is lower, that was obtained during the pre-endurance calibration. During maximum augmented operation, the duct heater fuel flow shall be adjusted so that, on a standard day, the total fuel flow will correspond to the level that was obtained during the initial calibration.

g. Final Acceptance Test

A final acceptance test, as specified in the current PWA Test Instruction Sheet for the JTF17 engine, shall be run. During this test the corrected jet thrust shall be not less than 95% of the initial calibration values, and the corrected specific fuel consumptions shall not exceed 105% of the initial calibration values. The engine shall meet all other specified performance requirements which can be checked by the calibration procedure. This run may be preceded by a run-in period during which the cleaning procedure recommended for field use by the engine manufacturer may be applied.

h. Reverser-Suppressor Endurance Test

In accordance with FAR 33.91, 33.97 and Advisory Circular 20-18A, the reverser-suppressor will be qualified by 150-hour sea level endurance test. This test will include 175 reversals from idle to maximum reverse thrust, and 25 reversals from maximum augmented thrust to maximum reverse thrust.

The initial 30 hours of endurance test described in Paragraph B.2.c and shown in figure 1 may be run on the endurance test engine. The remaining 120 hours of endurance will be conducted on an engine(s) assembled essentially to the production JTF17 Parts List. The endurance will consist of 30 cycles of 4 hours duration each with the power lever positions corresponding to the simulated flight conditions of the engine endurance test. This cycle is illustrated in figure 3.

The reverser-suppressor will be reinstalled on the Certification endurance test engine for the post-endurance calibration (Paragraph B.2.f) test.

C. PERFORMANCE DEMONSTRATION TEST

An instrumented engine assembled to the production JTF17 Parts List will be used in this test. The test will be conducted with inlet distortion representative of the SST and as defined in the Engine Model Specification.

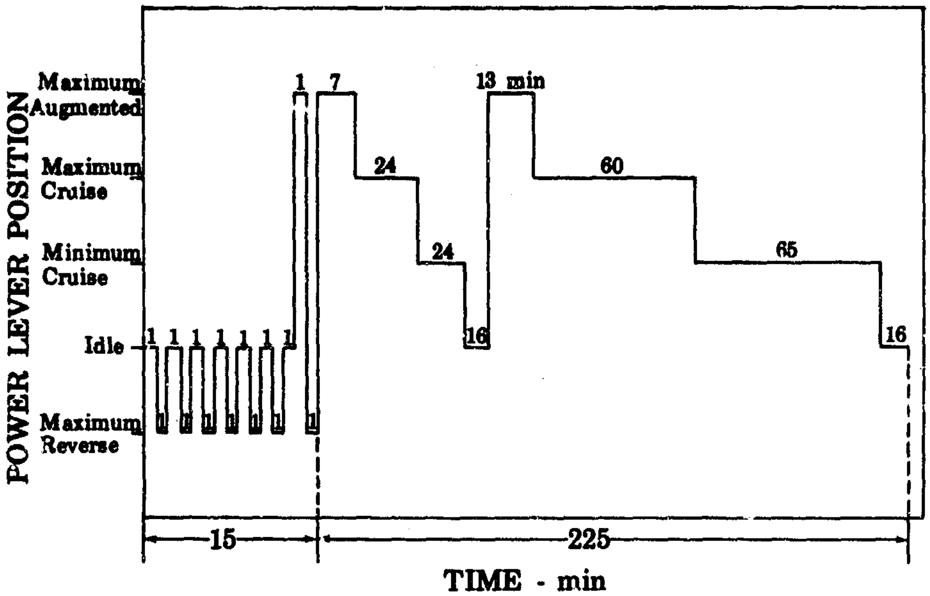

Figure 3. Proposed Reverser-Suppressor Cycle FD 17721 EVI

The test will entail an estimated 50 hours of altitude testing and will be conducted in an altitude test stand at FRDC. The test program will consist of the following:

1. Sea level calibrations from idle to maximum nonaugmented thrust in equal increments of thrust, from minimum augmented thrust to maximum augmented thrust in equal increments of duct heater fuel flow.

2. Altitude calibration of the engine at simulated flight conditions. Sufficient data will be taken to demonstrate the performance of the engine at the conditions specified in the Engine Model Specification.

3. Data for both sea level and altitude calibrations will be taken on automatic data recording systems and reduced to engineering units by digital computers. The corrections to the data will be as specified in the Engine Model Specification. Guarantee points as specified in the Engine Model Specification will be demonstrated.

D. MISSION CYCLE TEST

It is the design goal of the JTF17 engine to have an initial TBO of 600 hours. As a demonstration that the reliability and durability necessary to meet the 600-hour TBO has been achieved, an engine assembled essentially to the JTF17 production Parts List will be endurance tested. It is anticipated that 625 hours of endurance testing will be completed with normal maintenance, periodic hot section inspections, and field cleaning as required.

The test will be conducted in a heated inlet stand under simulated flight environmental conditions. The endurance program simulates a typical flight plan for the SST and is illustrated in figure 4. This program will be updated as further definition of the SST flight plan and environmental conditions are received.

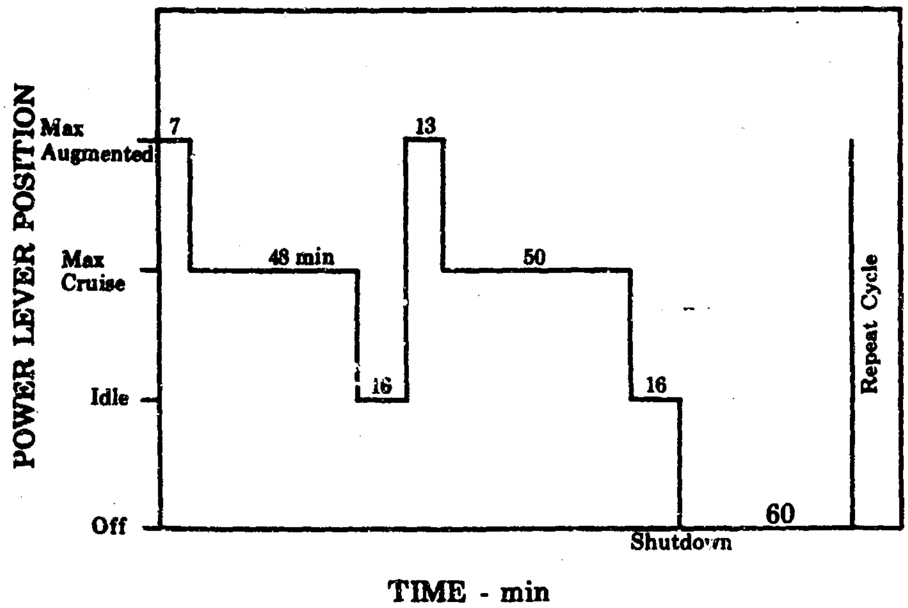

Figure 4. SST Typical Mission Cycle FD 16806 EVI

E. LOW CYCLE FATIGUE TEST

A realistic test program for low cycle fatigue must simulate the rate of change of inlet temperature, typical ascent and descent rates and allow sufficient time for the disk temperatures to stabilize at various operating conditions. The SST Typical Missions Cycle Test program, shown in figure 4, fulfills these requirements. The low cycle fatigue program will be run in conjunction with the Mission Cycle test.

The 625-hour mission cycle test described in Paragraph D subjects the rotating parts to 500 low cycle fatigue cycles (two low cycle fatigue cycles per mission cycle). Appropriate measurements of all disks, such as bore and rim diameters, will be taken before and after the test. All rotating parts shall be in satisfactory condition at the completion of the test.

F. THERMAL FATIGUE TESTS

A JTF17 engine assembled essentially to the production Parts List less the reverser-suppressor will be used in this test. The "hot section" parts will be assembled to the Parts List. The engine will be subjected to a 1000-cycle thermal fatigue test on a sea level stand. The cycle is illustrated by figure 5. Power lever changes will be made at a rate consistent with operating procedures in the SST. All "hot section" parts must be in a condition satisfactory to the FAA at the completion of the test.

A more complete description of the test is given in Section III.

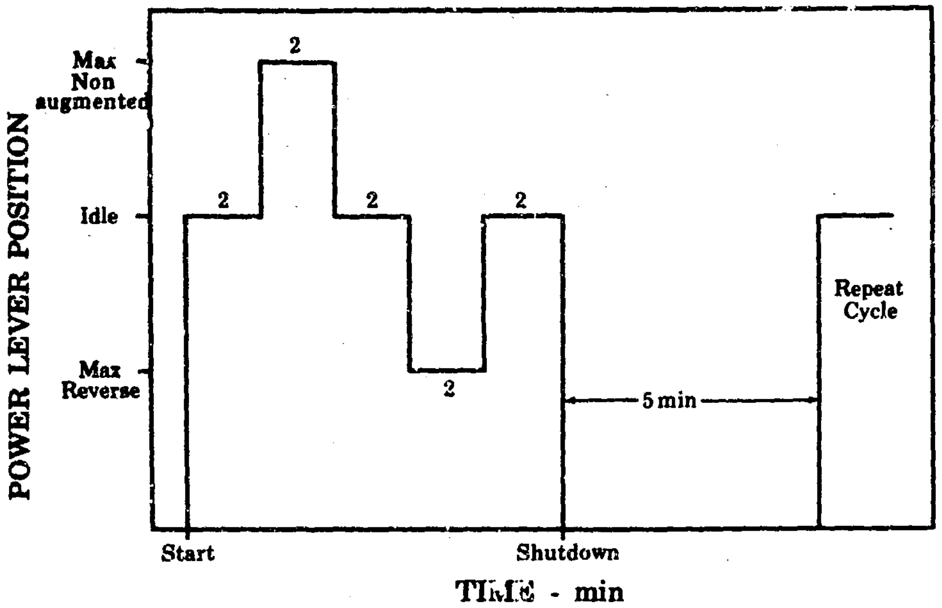

Figure 5. Thermal Fatigue Cycle

FD 16807
EVI

G. LOW AND HIGH ROTOR MAXIMUM ROTOR SPEEDS

This test will be conducted in accordance with FAR 33.87 and in conjunction with the Thermal Fatigue Testing, described in Paragraph F. An experimental engine assembly with all rotating parts to the Production JTF17 Parts List will be used in this test.

A 166-hour test will be conducted, as described in Paragraph F, consisting of idle, takeoff, and reverse thrust operating conditions. During this test, both low and high rotors will be maintained at their maximum normal operating speeds for each flight condition.

All rotor parts must be in usable condition at the completion of the test.

H. MAXIMUM EXHAUST GAS TEMPERATURE TEST

An experimental engine, assembled essentially to the production JTF17 Parts List will be used in this test. An abbreviated test consisting of the takeoff and climb portions of the 150-hour endurance test will be conducted on this engine at sea level conditions. The test cycle is shown in figure 6. This cycle will be repeated 30 times. All turbine section parts must be in usable condition after this test.

I. OVERTEMPERATURE TEST

An experimental engine assembled essentially to the production JTF17 Parts List will be used in this test. The test will meet the requirements of FAR 33.27 and Advisory Circular 20-26 and will be conducted in a sea level test stand. The test shall consist of running at least 5 minutes at a measured turbine exhaust gas temperature a minimum of 75°F over the maximum permissible turbine exhaust gas temperature.

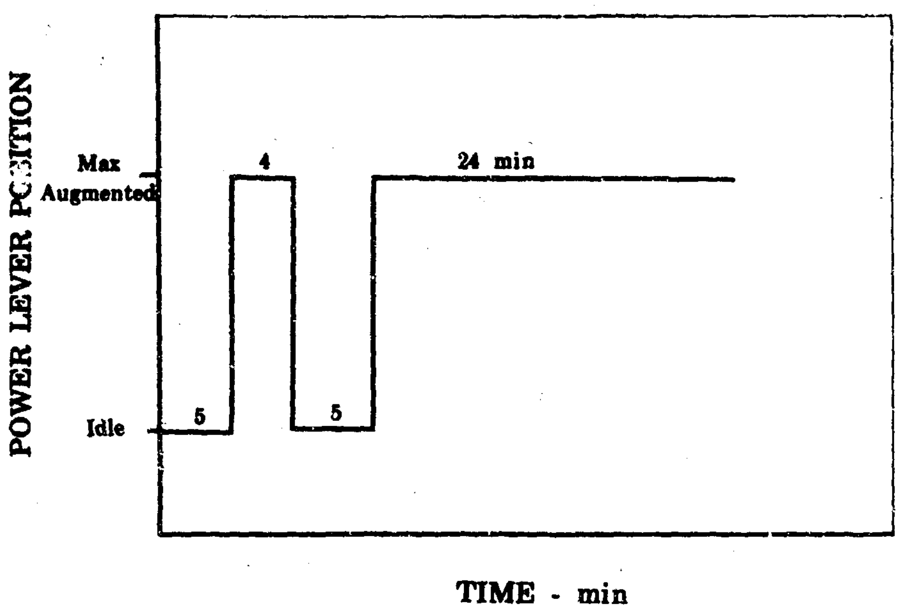

Figure 6. Maximum Exhaust Gas Temperature Test Cycle — FD 16808 EVI

J. AERODYNAMIC BRAKE TESTS

The JTF17 engine is equipped with an aerodynamic brake to reduce windmill drag, oil temperature during windmilling, and reduce the possibility of engine or airframe damage due to an unbalanced condition in the event of an in-flight shutdown. A self-contained system is provided to actuate the aerodynamic brake. In accordance with the proposed FAR 33.98, twenty-five actuation cycles of the aerodynamic brake from normal engine operating position will be completed. Each cycle will be initiated with the engine at stabilized windmill speed at cruise condition of Mach 2.7 at 65,000 feet.

The engine used in this test will be aerodynamically the same as the production Parts List JTF17 engine. The aerodynamic brake parts must be in satisfactory condition for reuse after this test.

K. FOREIGN OBJECT INGESTION TESTS

Foreign object ingestion tests will be conducted on a JTF17 engine assembled essentially to the production JTF17 Parts List. Tests will be conducted in accordance with FAR 33.13, Proposed FAR 33.77 and Advisory Circular 33-1. These tests will be conducted on a sea level test stand with necessary instrumentation to determine the effect of the foreign object ingestion on engine performance and reliability. High speed motion pictures will be taken of the engine during the ingestion tests to evaluate physical effects on the engine.

Design features incorporated in the JTF17 engine which minimize effects of foreign object ingestion are:

1. Absence of inlet guide vanes
2. Double shrouded 1st and 2nd fan blades and shrouded blades in the first stage of the high compressor
3. Appreciable clearance between rotor blades and stator vanes, to allow for deflection of blades
4. Blade containment features in the fan and compressor cases
5. Rotor integrity with 10% adjacent blade loss in any rotor stage.

The following foreign objects will be ingested into the engine on a sea level test stand at the simulated operating conditions shown:

Engine Operating Condition	Simulated Flight Speed	Foreign Object
Sea Level Takeoff	Zero	Mechanic's hand tool, pocket size; two small aircraft steel nuts and bolts
Climb Thrust	Subsonic	2 - 12 X 12 X 1/2 inch Ice Slab. 8 each of 1 and 2 inch diameter ice balls. 16 - 2 to 4 oz. birds. 8 - 2 to 4 lb. birds
Transonic Thrust	Transonic	8 - 1/2 in. diameter ice balls.

L. ENGINE INLET ICING TESTS

This test will be conducted in accordance with FAR 33.67b. A JTF17 engine assembled essentially to the production parts list will be subjected to icing tests at idle and low thrust conditions corresponding to descent and subsonic hold conditions for the SST and in accordance with conditions specified in FAR 25, Appendix C.

A complete description of this test is given in Section III.

M. DISK OVERSPEED TESTS

Overspeed spin tests will be conducted in a hot whirl pit on representative disks of the fan, high compressor, low turbine and high turbine of the JTF17 engine. The test will be conducted in accordance with FAR 33.27 and Advisory Circular 20-26.

Disks will be spin tested to 120% or greater of their normal maximum rated speed for a period of not less than 5 minutes while at the engine operating temperatures for the disk being tested. The disk temperature data are obtained from thermocouples while operating the engine at cruise conditions. This

testing is described in Section III. Dummy blades will be installed to simulate engine operating loads. Disks are heated to operating conditions by heating coils contained in the spin pit. The selection of the disks to be tested will be made on the basis of design criteria (creep, burst, yield, etc.), material (titanium, Waspaloy, Astroloy, etc.), operating conditions (temperature gradient, average temperature, stress level, etc.) and configuration (integral spacer disk, flat disk, etc.). Although Phase III results may dictate otherwise, it is anticipated that the flat high compressor stage 4 and 8 disks of Waspaloy (PWA 1016) and the integral spacer high compressor stage 7 disk of Waspaloy (PWA 1016) will be spin tested thus including the maximum and minimum operating temperature for the disks. Instrumentation will be installed to ensure the proper operating conditions are maintained during the spin tests.

The disks must be in a reusable condition after this spin test.

N. GEARBOX TEST

In accordance with FAR 33.91, the gearbox will be substantiated by the engine endurance test, described in Paragraph B and by a separate environmental endurance test. The engine endurance test will include the gearbox with its normally engine-mounted accessories as defined by the Parts List, such as main fuel pump, oil pump and engine hydraulic pump overhung weights on other drives. A 150-hour test will be conducted at sea level and at simulated altitude Mach numbers conditions. The gearbox parts must be in usable condition at the completion of this test.

Since the gearbox is not fully loaded in the engine test, a separate endurance test will be conducted on a Parts List gearbox. A typical test, illustrated in figure 7, consists of fifteen endurance cycles at conditions approximating those anticipated in the SST. The gearbox will be run at the maximum speeds with the drives loaded to the maximum permissible torque ratings specified in the Installation Drawing. Overhung moments of the accessory pads will be simulated by airframe supplied accessories or by dummy weights. The typical test will be updated as better definition of the typical mission of the SST is received and is subject to approval by the FAA prior to the start of the Certification test.

After completion of the endurance test the gearbox parts must be in a usable condition per FAR 33.93.

O. FAN, COMPRESSOR AND TURBINE ROTOR STRESS DEMONSTRATION

This test will be conducted in accordance with FAR 33.27 and Advisory Circular 20-26 and will be conducted on full-scale experimental engines assembled essentially to the production JTF17 Parts List and on component test rigs. The vibratory stresses measured in the disks and blades of all stages of the JTF17 engine at all operating conditions must be within the design limits.

1. Fan Stress

The stress levels of the fan disks and blades will be recorded in both full-scale rigs and full-scale engines. Rig tests will be conducted over the full operating range of the fan at ambient temperatures conditions. Stress levels

of disks and blades will be recorded by means of strain gages. Stress levels of the fan disks and blades will be recorded and must be within normal limits at sea level takeoff, subsonic, transonic, and supersonic flight conditions in a full-scale JTF17 engine.

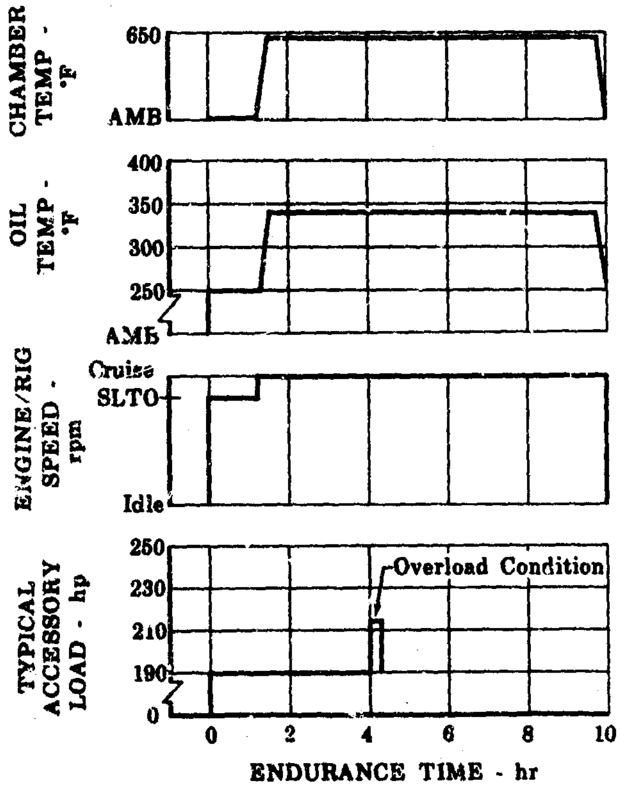

Figure 7. Typical JTF17 Gearbox Cycle Certification Test — FD 16809 EVI

2. High Compressor Stress

The high compressor disks and blades stress levels will be measured in the following manner. The stress levels must be within normal limits.

1. High compressor component test rigs operating at normal sea level ambient temperatures.
2. High spool component test rig operating at simulated cruise conditions.
3. Full-scale engine testing at sea level, transonic and cruise conditions.

3. Turbine Stresses

The turbine disks and blades stress levels will be measured in rigs and full-scale engine testing. Testing will cover the entire operating range of the engine. This includes sea level takeoff, reverse operation, transonic and cruise conditions Initial testing on the high turbine will be conducted on the high spool rig, as

described in Volume III, Report E, Section II. Further testing will be conducted in full-scale engines utilizing intershaft slip rings or a telemetry system for high turbine data transmission and a normal slip ring installation for low turbine data transmission. The stress levels must be within normal limits.

P. BLADE CONTAINMENT

Blade containment will be demonstrated on the JTF17 engine in accordance with FAR 33.19 and Advisory Circular 33-1. The tests will be conducted on full-scale engines as well as rigs which have cases essentially to the Parts List design. Containment will be demonstrated for the engine with all critical cases at or near their maximum normal operating temperatures.

During the development program of the engine and components, there will undoubtedly be blade failures resulting from testing at overload, overtemperature, high stress levels, and the like. These failures will probably occur at a variety of conditions from sea level to cruise environment. The failures that do occur will provide the basis for demonstration of the containment ability of the JTF17 engine.

Q. OIL TANK TEST

The JTF17 engine oil tank will be tested in accordance with FAR 25.1015. The oil tank will be pressure tested with engine oil at 250°F at 5 psi or more above the maximum pressure differential permitted during normal engine operation as specified in the Engine Model Specification. The oil tank shall show no evidence of distortion or leakage.

R. COMPONENT SUBSTANTIATION TESTS

The fuel control system components will be substantiated by the engine endurance test described in Paragraph B.

S. TURBINE ROTOR COOLING DESIGN

The cooling system for the turbine rotor, including disks and blades, of the JTF17 engine is designed with fixed orifices to meter cooling air flow to the various components. The minimum orifice size used, with the exception of the cooling holes in the individual blades and vanes, is 11/32 inch diameter. The minimum hole size used in the individual blade and vane cooling schemes is no less than the minimum size successfully operating in the J58 engine.

T. CONTAMINATION TESTS

A contamination test will be conducted on an experimental JTF17 engine instrumented for performance testing. This engine will be built essentially to the production Parts List less the reverser-suppressor. Testing will be conducted on a sea level test stand. A sand-dispensing hopper will be mounted in front of the engine discharging uniformly into the engine inlet. The contamination test will be conducted as follows:

1. Pre-test calibration
2. 10-hour contamination run
3. Post-test calibration

A pre-test calibration of the engine will be run from idle to maximum augmented thrust. Data will be taken in approximately equal thrust increments from idle to maximum nonaugmented thrust, and from minimum augmented to maximum augmented thrust in approximately equal increments of duct heater fuel flow. The gas path instrumentation will be removed after this calibration except for turbine discharge pressure and temperature probes.

With the engine operating at maximum cruise nonaugmented thrust conditions, dust, conforming to AC Spark Plug Part number 1543094 will be ingested into the engine at the rate of 0.005 grams per cubic feet of air. The rate and type of contaminant is as specified in MIL-E-5009B, Paragraph 4.3.2.3.3.1.1. A total of 10 hours of operating at these conditions will be conducted.

A post-test calibration will be conducted, with instrumentation, in the same manner as the pre-test calibration. During this test the engine shall be adjusted to produce on a standard day the nonaugmented thrust or maximum turbine discharge temperature, whichever is lower, that was obtained on the pre-test calibration. The duct heater fuel flow shall be adjusted so that, on a standard day, the total fuel flow will correspond to that obtained on the pre-test calibration. The corrected jet thrust shall not be less than 95% of the pre-test calibration and the corrected specific fuel consumption shall not exceed 105% of the pre-test calibration.

Inspection of the turbine section after completion of this test shall show no detrimental effects due to the contamination. In addition to this test, during the normal development program of the engine and components, cooling air system contaminants such as dust and sand will be ingested into the engine, thus demonstrating the ability of the JTF17 engine to withstand contamination of the turbine cooling system.

U. ENGINE SYSTEMS FAILURE ANALYSIS

In accordance with the proposed revision to FAR 33, Paragraph 33.75, the design and functioning characteristics of the complete engine and its associated engine systems will undergo a complete failure analysis. This analysis includes the effects on safety of possible malfunctions, failures and likely maloperations. A sample sheet of a typical failure analysis is shown in figure 8.

V. CONTROL SYSTEM FAILURE ANALYSIS

A control system failure analysis will be conducted on the JTF17 fuel control system in accordance with the proposed FAR 33.75. This failure analysis is covered in detail in Volume III, Report B, Section III. Sample sheets of the failure and safety analysis are shown in figures 8 and 9.

Sheet 1

JTF17 FAILURE MODE & EFFECT ANALYSIS

No.____of____

Item	Function	Failure Mode	Failure Effect on Subsystem	Method of Detection	Failure Effect on Engine	Failure Effect on Aircraft	Crew Action Required

Analyzed by: ____ DESIGN DATE ____ RELIABILITY DATE ____ PROJECT DATE

Figure 8. Sample of JTF17 Failure Mode and Effect Analysis, Sheet 1

Sheet II

JTF17 FAILURE MODE & EFFECT ANALYSIS

No.____ of ____

Item	Function	Failure Mode	Hazard Classification I	II	III	IV	Design Philosophy To Preclude Failure	Design Philosophy To Reduce Hazard

Analyzed by: ____ DESIGN DATE ____ RELIABILITY DATE ____ PROJECT DATE

Figure 9. Sample of JTF17 Failure Mode and Effect Analysis, Sheet 2